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ERONAUTICAL PRACTICE

PART I

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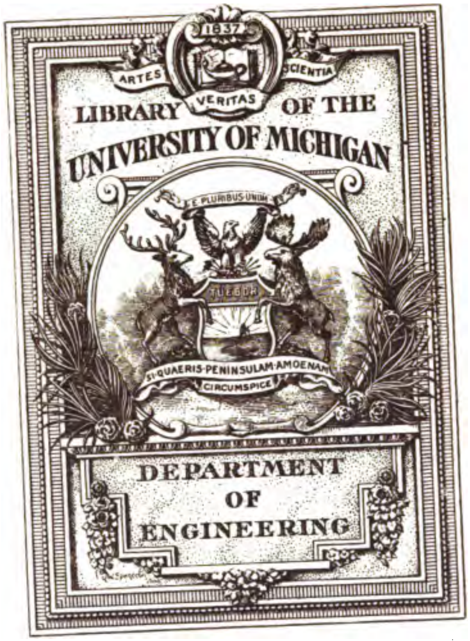

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AERONAUTICAL PRACTICE

PART I

INSTRUCTION PAPER

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AERONAUTICAL PRACTICE

PART I

STABILITY OF THE AEROPLANE

Variations of Center of Pressure. When an aeroplane of any shape is placed at various angles in a current of air, it is found that the point at which thepressure acts, *i.e.*, the center of pressure, varies with every inclination. This variation or travel of the point of application of the center of pressure differs with every section and plan shape of aerocurve or aeroplane. With certain aerocurves and with all aeroplanes the center of pressure appears to travel continuously toward the front edge as the inclination is continuously decreased. In Fig. 1 is shown the locus of the center of pressure for rectangles having an aspect ratio of three to one in length and width aspects. In both cases the center of pressure continuously advances with decrease of inclination.

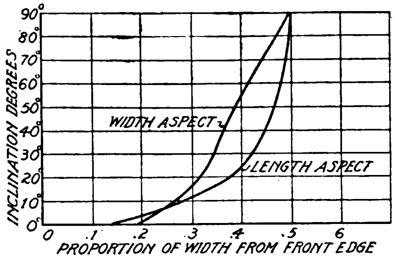

Fig. 1. Center of Pressure Curves for Rectangular Planes. Aspect Ratio 3 to 1

Fig. 2 shows a similar locus for an aerocurve having a camber of $\frac{1}{12}$ span, and an aspect ratio of 3 to 2, curve 2 representing the hollow upward and curve 1 the hollow downward. The curve 2 indicates strong stability, and the curve 1, an absence of stability. These and the following curves of the center of pressure were taken $\frac{3}{16}$ inch above the highest point in the plane, the greatest dimension of the plane being 9 inches. A. P. Thurston, who made the series of experiments here recorded, found it preferable to obtain corresponding curves in

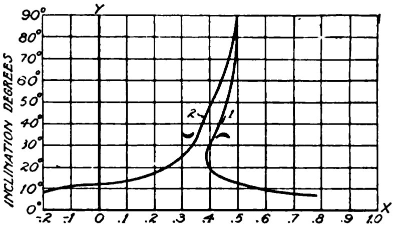

Fig. 2. Locus of Center of Pressure at Different Inclinations

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addition below the planes, since the resultant pressure becomes more inclined to the normal as the inclination of the plane is decreased. Then, by the combination of the two curves so obtained, it is possible to find the travel of the center of pressure for any other parallel line. The stability of a flying machine depends upon the continuous travel of the center of pressure toward the front edge with decrease of inclination.

Conditions for Stability. The center of gravity and the center of pressure coincide under normal conditions when a flying machine is running at the natural angle and speed, but when the angle is too small, the center of pressure approaches the front edge and forms, with the weight, a couple tending to restore the machine to its natural inclination. Conversely, if the inclination be too great, the center of pressure travels behind the center of gravity and forms a couple tending to decrease inclination. It follows, as the first necessary condition for maximum stability, that the travel of the center of pressure to either side of the center of gravity should be a maximum for a minimum alteration in the angle of inclination.

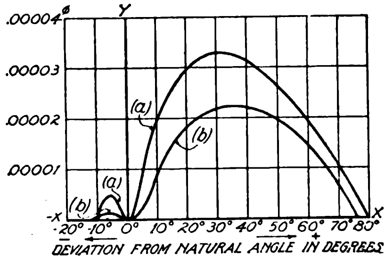

Fig. 3. Stability Curves for Rectangular Planes

As the second condition, it follows that the moment of inertia of the machine about a lateral axis through the center of gravity should be a minimum, since the inertia of the machine resists the action of the restoring couples. The restoring couple at any point is the product of the lift by its distance from the vertical through the center of gravity. Since the lift is a function in the equation of stability, it follows, as the third condition for maximum stability, that the decrease of lift with decrease of inclination should be a minimum. In the ideal condition, the lift should increase as the inclination is decreased from the natural angle. This is, of course, impossible in practice. If, when a machine has received a small displacement from the natural angle, a perpendicular through the center of lift is drawn to cut the line which passes through the center of gravity and which is perpendicular when the machine is at the natural inclination, a point is obtained the position of which affects the stability of the machine. This point, which, to coin an expression, might be called the "phugoid center" corresponds to the metacenter of vessels, and its height above the center of gravity gives a measure of the longitudinal stability of a flying machine.

In Figs. 3 and 4 are shown the stability curves of rectangular planes having aspect ratios of 3 to 1 in length and width aspects, respectively. Models were made and the centers of gravity carefully adjusted until the best flights were obtained. Good flights were obtained with center of gravity located 0.28 of the width from the front edge. The models were then pivoted about these points, and the vertical torque resisting a displacement from the natural inclination was measured; this is plotted in Figs. 3 and 4. Fig. 4 is an enlargement of a portion of Fig. 3. Curve *a* shows the plane in the length aspect, and curve *b* in width aspect. The rectangle in length aspect clearly has a much greater stability than the same rectangle in width aspect. The restoring torque is $\phi W A V^2$ pound feet, ϕ being the stability coefficient for any deviation from the natural flying angle and read from the diagrams, Figs. 3 and 4; W the width of plane in feet, back to front, taken in the direction of motion; A the area in square feet, and V the velocity in miles per hour.

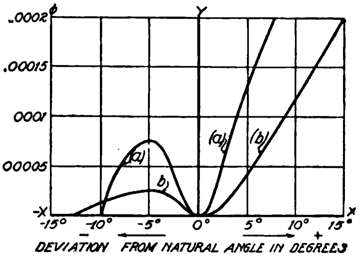

Fig. 4. Stability Curves. Enlarged Detail of Fig. 3

Methods of Increasing Stability. The stability of a machine may be increased by placing a second or rider plane in front of or behind the main plane. For maximum efficiency in flight, the main plane should have the shape and area giving the maximum lift efficiency, *i.e.*, it should be approximately a rectangle in length aspect. The shape of the main plane being thus fixed, it is possible to vary the shape and disposition of the rider plane only for the purpose of increasing the stability. Now the travel of the center of pressure might be increased if it were possible to cause the pressure on a front rider plane to decrease at a less rate than the pressure on the main plane, and, conversely, with a tail rider plane, to decrease at a greater rate than that on the main plane. This result may be obtained by each or all of the following means;

Placing a front rider plane at a positive angle with the main plane, i.e., at a greater angle to the air than the main plane, and a rear rider at a negative angle, i.e., at a less angle.

By utilizing the wake of the front plane to affect the back plane.

By the use of certain shapes and aspects of planes for the front and rear riders, respectively.

Front and Rear Rider Plane. If the front rider is at a positive angle, then, as the inclination decreases, it is obvious that the pressure on the main plane will decrease at a greater rate than that on the rider, since the rider will still be lifting when an angle is reached at which the main plane ceases to lift. Conversely, if the rider is set at a negative angle, then, as the inclination of the machine decreases the front plane will reach an angle at which it ceases to lift, and upon a still further decrease in inclination the air will act upon the top of it and introduce a depressing force. This force will oppose the couple introduced by the travel of the center of pressure. Thus it follows that the front rider should be set at a positive angle with the main plane. From a similar reasoning it follows that a tail rider should be set at a negative angle with the main plane. It will be evident that the original arrangement of the Wright machine with the front rider at a negative angle tended to decrease the natural stability of the biplane, and this was probably one of the causes that led to its abandonment.

"Wake Effects." Too little attention appears to have been paid to the utilization of the wake effects for increasing the stability. The air which is engaged by an aeroplane is deflected downward. This downward deflection is not confined to the air in the immediate run of the aeroplane, but extends to a considerable distance above and below the plane, particularly above. The field of an aeroplane is therefore greater than its run.

A series of original stream-like photographs taken with the aid of smoke in a current of air having a speed of 1,800 feet per minute demonstrated this very clearly. The stream of air flowed out of a small nozzle so that it could be positively directed at any point desired, the surfaces experimented with being models of the single and double surface elevating planes such as are employed on the majority of standard type monoplanes and biplanes. With the monoplane elevator set at a sharp positive angle and the current directed horizontally, the air considerably above the plane was noticeably influenced, while when directed straight at the edge of the plane the air divided in front of it, closely hugging the under side and forming a "surface of discontinuity" on the back. Directing it at the center of the plane, the angle of incidence being the same in every case, clearly showed the compression under the plane as well as the upward spring of the current at the rear to counteract the suction above; and directing the stream below the plane showed the gentle downward deflection imposed on the air below the rear edge of the plane, indicating that the air entirely below the plane is affected quite as much as that above it. From these experiments it will be apparent that the air at the rear of an aeroplane is in a considerable state of agitation which varies from point to point. Now the lifting effect of this air in the wake is not so good as that of undisturbed air; moreover, since this air has on the average a downward deflection, an effect is obtained on the rear plane similar to that obtained by placing it at a negative angle with the front plane. Thus the stability may be increased by placing the rear plane in the wake of the first plane; but there is an additional effect to be obtained by utilizing the wake.

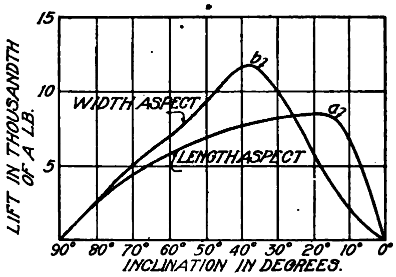

Fig. 5. Lift on Planes at Various Inclinations. Planes 3 × 1 Inches, Velocity of Air 21 Feet per Second

The purpose is to arrange it so that the lift on the rear plane shall decrease at a greater rate than that on the front plane. Since the lifting effect of the wake is not so good as that of undisturbed air, it follows that this object may be attained by arranging the rear plane to enter the wake when the inclination is decreased, and to come out of it into the free air when the inclination is increased. The best place for mounting the rear plane to obtain the maximum effect by this means can be determined only by experiment and by drawing the stability curves, as in Figs. 3 and 4, and the curves for the travel of the center of pressure, as in Figs. 1 and 2.

Rider Planes of Certain Shapes and Aspects. The third method of increasing the stability is by the use of rider planes having certain shapes and aspects; for instance, these shapes may take a square, rectangular, circular, semicircular, triangular, or other plan form. Of these a rectangle in length aspect and having the greatest aspect ratio has a greater lift per unit of area at small angles than any other shape. In Fig. 5, which is derived from Dr. Stanton's experiments on a plane having an aspect ratio of 3 to 1, the lift on the plane in length aspect at angles between zero and 20 degrees (see curve *a*) is much greater than that on the plane in width aspect (curve *b*). Moreover, for angles above 20 degrees the pressure decreases proportionately (curve *a*) at a less rate than in the case of the same rectangle in width aspect (curve *b*). Therefore, a rectangle in length aspect, and having a large aspect ratio, is the best shape for a front rider. The shape of planes having the greatest proportional decrease with inclination appears to be either a triangle with its apex to the wind, or a rectangle in width aspect. The superiority of the triangle in this respect has not been fully demonstrated by experiment, but it has proven unusually successful in some of the French monoplanes such as the Antoinette. It is clear that there is a greater proportional decrease with inclination for planes having a smaller width aspect. Therefore, it follows that the tail planes should have a smaller aspect ratio than the front planes.

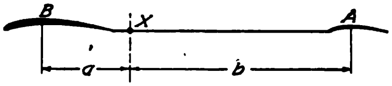

Fig. 6. Main and Tail Planes

The center of area of a triangle with its apex to the wind would be farther from the center of gravity of the machine than the center of area of a rectangle of equal area in width aspect. A greater restoring torque would, therefore, be obtained. Moreover, for equal areas of tail plane, a triangular tail would have double the span of a rectangular plane, and, therefore, take approximately double the advantage of the wake effect. It would thus appear from these considerations that a tail rider plane should preferably be triangular, with the apex toward the wind. Conditions represented by curves *b* and *c* (see Fig. 11) appear to require aspect ratios of opposite values; thus it follows that the relation of the dimensions should be fixed by experiment.

Methods of Producing Effective Damping Couple. The problem of stability is not completely solved by the provision of a suitable restoring couple. It is necessary to provide, in addition, an efficient damping couple to damp out any oscillation which may be set up. This damping couple is provided by the resistance offered to the planes as they oscillate in the air above the center of gravity of the machine. If, in Fig. 6, *A* equals area of the tail plane, *B* equals the area of the main plane and *X* is the center of gravity of the system, then $A \times b$ equals $B \times a$. Therefore, since the areas of both planes *A* and *B* are constant, the distances *a* and *b* must also be constant. For a given angular velocity of oscillation about the center of gravity *X*, the velocity *v* of the plane *A* is proportional to the distance *b;* and furthermore the resistance offered by the air to a plane is proportional to the square of the velocity. Therefore, the damping couple introduced by the rider plane *A* equals resistance $\times b$, *i. e.*, $v^2 \times A \times b$. But it has already been sated that *v* is proportional to *b* and, therefore, the damping couple is proportional to Ab^3 or to $Ab(b^2)$; *i.e.*, the damping couple provided by rider planes having equal control torque increases as the square of the distance from the center of gravity: The distance between the planes should, therefore, be as large as is practicable, which doubtless accounts for this characteristic of the most successful French monoplanes, such as the Bleriot, in which the fuselage or tail is extremely long. Also it follows that a triangular tail gives a more powerful damping action than a rectangular width aspect tail. From the previous reasoning it would appear that for maximum longitudinal stability,

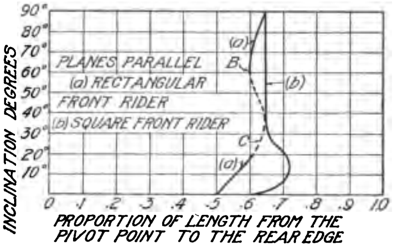

Fig. 7. Center of Pressure Curves for Plan Shapes of Figs. 8 and 10

(1) With the rider plane in front, the rider should have a large aspect ratio in length aspect, and a long span approximating to that of the rear main plane.

(2) With the rider plane behind, the rider should have a smaller aspect ratio than the front main plane, and should preferably be triangular with the apex toward the wind and placed so as to take advantage of the wake effects.

(3) In both cases the rider plane should be set as far as possible (within limits) from the main plane, the planes should be set at a positive angle with each other, and the moment of inertia of the machine should be a minimum.

Study of "Center of Pressure" Curves. Center of pressure curves for flying machines of various plane shapes and dispositions are shown in Figs. 7, 8, 9, 10, and 11. In all these cases the main plane is rectangular, 9 by 2 inches, the aspect ratio is thus 4½ to 1. This rectangle is fixed to one end of a rib with its length at right angles. The rider planes are adapted to be pivoted at the other end of the rib 7 inches from the outside long edge of the main plane. The curve *a*, Fig. 7, is obtained with a front rider plane 9×½ inch in length aspect. Its aspect ratio is therefore 18 to 1. Curve *b* is a corresponding curve with a square front rider of equal area to the last. In both cases, the rider and main planes are parallel. The increased stability obtained by the rectangular rider is apparent. If allowance is made for the increased longitudinal length of the model with a square front rider, the superiority of the rectangular rider is still more marked. Curve *a* between the points *B* and *C* was found to be unstable, it being found impossible to obtain definite points of balance.

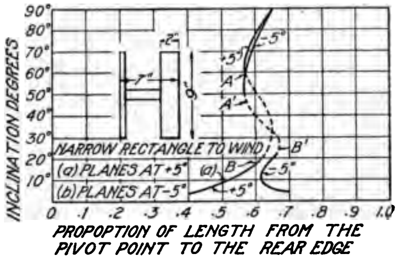

Fig. 8. Center of Pressure Curves for Plan Shape Inset

Fig. 8 shows curves *a* and *b* obtained with the first model, having the rectangular front rider at a positive and negative angle of 5 degrees, respectively. Curve *a* is obtained with the rider at plus 5 degrees with the main plane. This disposition gives a strong stability. In curve *b*, with the rider set at a negative angle with the main plane, there is a lack of stability, the center of pressure traveling toward the rear for all decreases of angle below 13 degrees. The curves were also found to be unstable between the points *A*, *B*, and *A'*, *B'*.

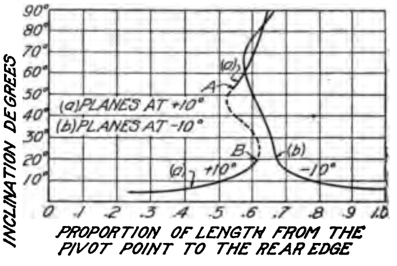

Fig. 9. Center of Pressure Curves for Plan Shape of Fig. 8

Curves *a* and *b*, Fig. 9, show the same model with the rectangular front rider at plus 10 degrees and minus 10 degrees, respectively.

Curve *a*, with the rider at plus 10 degrees, shows a stronger stability than the previous curve *a* of Fig. 8, and curve *b* shows a correspondingly greater lack of stability. Again it was found impossible to obtain definite reading between the points *A* and *B*, but no such difficulty was found with curve *b*.

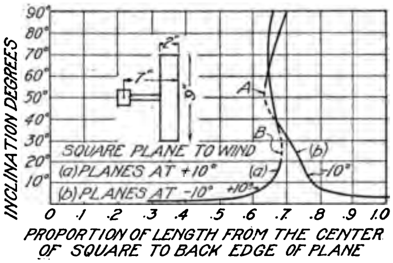

Fig. 10. Center of Pressure Curves for Plan Shape Inset

Fig. 10 shows curves corresponding to those in Fig. 9, but with a square front rider of equal area. The planes are set at plus 10 degrees and minus 10 degrees, respectively, in curves *a* and *b*. These curves are very similar in characteristic shape to those of Fig. 9, but in neither case is the stability or instability so strongly marked. The portions of the curves indicating the stability lie between 3 and 15 degrees. It is clear that the travel of the curves between these inclinations is smaller in Fig. 10 than in Fig. 9. Curve *a* is discontinuous between the points *A* and *B*.

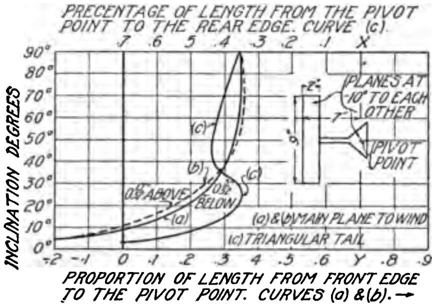

Fig. 11. Center of Pressure Curves for Bleriot Plan Shape Inset

Fig. 11 shows the center of pressure curve for a Bleriot disposition with a rectangular main plane and a triangular tail rider. The planes are in all cases at plus 10 degrees to each other. Curve *a* shows great stability. The center of pressure travels in front of the front edge of the main plane. The equilateral triangular plane is pivoted at its centroid and has an area equal to the square and rectangular riders previously used. It is mounted at the rear of the main plane with its apex to the wind. In curve *a* the triangular plane is mounted $\frac{9}{32}$ inch below the main plane and in curve *b* $\frac{11}{32}$ inch above. The difference in the curves *a* and *b* is therefore to be attributed solely to the wake effects. Curve *a* gives a superior stability to curve *b*. Curve *c* is obtained with the model used in curve *a* with the same angle, the current being reversed. Thus the main plane becomes a rear plane, and the triangular tail a front elevator with its base to the wind. The line *X Y* is the vertical base line for this curve, and corresponds with the back of the main plane. Curve *c* has been superposed on curves *a* and *b* to show the effect of plane shape and disposition on the travel of the center of pressure and the stability. These experiments were carried out in the aerodynamical laboratory of the University of London.

It will be apparent that the problem of stability resolves itself into keeping the center of pressure and the center of gravity in the same vertical line while sailing through the rolling masses of air that constitute every wind, the principle being exactly the same as in the dirigible although in the latter the putting it into practice is not attended by as many complications. The first investigators tried to do this in their gliding experiments by shifting their weight while gliding, but found it a difficult and, at times, an impossible task. For instance, Lilienthal, after making more than a thousand successful glides, was overturned and killed. The first successful departure from this crude method was that of the Wright Brothers who employed a horizontal rudder or rider some distance in front of the main plane, by which the machine could be prevented from overturning frontward or backward. This principle—that of operating stabilizing planes to overcome or to counteract every variation of the position of the center of pressure due to changes in the velocity and direction of the wind as originated by the Wrights —was what made flying possible, and it is now employed on every successful aeroplane. As demonstrated by the experiments just recorded, however, it was found that the front rider did not take advantage of the wake effects and was not as efficient a preserver of stability as the rudder in the rear; later Wright machines all were built in this manner, the only surfaces forward of the main planes being two small, fixed fins or keels to give greater inherent lateral stability. In all monoplanes, the stabilizing surfaces are at the rear and some distance behind the main plane, it being possible to reduce the area of these surfaces in proportion to the increased leverage afforded by their greater distance from the main plane.

With the elevators and stabilizing planes of moderate size and placed at moderate distances from the center of gravity, the balance of the aeroplane may be kept under control in the most irregular winds, provided these auxiliary surfaces are always set at the proper angle to give the desired restoring effect as determined by the rapidly shifting conditions. But when it is recalled that, at times, even the birds are upset by gusts of wind, and sometimes fall to the ground before they can recover their equilibrium, it is not surprising that occasions should be encountered in which the most experienced aviator is not quick enough to set the rudders to meet every gust. It is, therefore, essential that the aeroplane should be possessed of sufficient inherent stability to supplement the aviator's efforts in times of emergency, or that it be equipped with a controller which will automatically adjust the balancing surfaces independently of the aviator. The latter is a subject that is at present engrossing the attention of many of the foremost investigators in this field and it is treated of in detail under the head of Automatic Stability.

Longitudinal and Lateral Stability. The principle on which the inherent fore-and-aft, or longitudinal stability of an aeroplane depends is comparatively simple. The center of gravity of the machine is placed in front of the normal center of air pressure, and the forward planes are inclined at a greater positive angle to the line of flight than the following planes. If an aeroplane so adjusted be allowed to fall from a great height, since the center of gravity is forward of the normal center of pressure, the front will turn down and the machine will dive toward the ground. Then, when it has gained sufficient speed from gravity, since the forward rider has a greater angle of incidence than the main planes, the front receives a proportionately greater air pressure and the machine rights itself. This is strikingly illustrated by the foolhardy performance variously termed the "high dive" and the "dip of death," practiced by professional aviators at public meets, in which the machine is allowed to descend from a height of 1,500 to 2,000 feet at an angle of 45 to 60 degrees until it has attained a terrific speed, and then suddenly tilting the elevating planes when within a few hundred feet of the ground, thus bringing the machine up sharply, on an even keel, and incidentally putting a frightful strain on every part of the aeroplane. As soon as the front of the aeroplane turns up again, its speed diminishes until the front again drops, and in this manner its flight through the air may be kept constant when driven by the motor. What is commonly known as "volplaning"—descending from a height without the motor, is simply a succession of these dives, followed by alternate periods of sailing on an even keel or at a slight upward angle.

There are two different principles by which inherent lateral stability is secured. The first of these is simply to arrange the main supporting surfaces at a dihedral angle, or to use vertical surfaces, *i.e.*, fins or keels, with a low center of gravity. Both of these constructions give the same result, viz, the air pressure on the lower side is increased, thus causing it to rise. The other method is somewhat more complicated for, in this case, there must be a vertical plane at some distance behind the center of gravity. If, with this arrangement, the aeroplane tilts to one side, it will slide sideways until the air catches the vertical plane in the rear and turns it head into the wind. The result is that instead of upsetting, the aeroplane simply wings around. If there be a constant upsetting force, however, the radius of the circle becomes smaller and smaller and, unless corrected by the controlling planes, the machine strikes the ground banked at a steep angle. But this principle works fairly well even in high winds and is employed on the majority of successful aeroplanes. A typical instance of its use is found in the Antoinette monoplane in which a large vertical surface is combined with a triangular elevator at the extreme end of a long tail frame or fuselage.

However, though an aeroplane may maintain its balance in still air in this manner, when winds arise troubles arise with them and for that reason the beginner is always cautioned never to attempt a flight in a power-driven machine except when there is an absolute calm. Since the stability of the machine depends upon the reaction of the air upon it when gravity pulls it one way or the other, the balance is disturbed whenever it is struck by wind gusts. For instance, just as when the aeroplane flies too rapidly through the air it turns upward until its velocity decreases, so if a wind strikes it in front its speed through the air is increased and the front turns up and if the wind comes from behind its speed is decreased and it turns toward the ground. If the wind gust is sharp and the aviator is flying low, he may strike the ground before equilibrium can be recovered, and not a few aviators have either been seriously injured or killed in this manner, it being thought that a condition of this nature was responsible for the death of Moisant whose machine suddenly plunged to the earth from a height of only one hundred feet.

It has been determined by innumerable experiments with every type of model, that, in general, the closer the centers of gravity and pressure coincide, the less the longitudinal stability is influenced by variable air currents. It is almost impossible for a well-balanced aeroplane to be completely overturned while in the air, but it may easily be tipped to an angle which is very dangerous, especially when close to the ground. This method of obtaining stability is the only one in common use up to the present, but it has been noted that while it works very well in calm air, it may become a source of danger rather than of safety when used in gusty winds. If every time the aviator comes within one hundred feet or less of the earth he is in danger of being dashed precipitately to the ground, the aeroplane can scarcely be considered a practical or safe machine. As has already been noted, the designers of successful machines have provided ample area in the stabilizing surfaces to counteract extremes of movement of the center of pressure caused by variations of wind velocity and direction, so that if it be possible in any manner to cause these balancing planes to act of their own accord to counteract changing conditions as rapidly as they arise, perfect equilibrium in the most sharply varying winds will be attained. This in brief is the problem of automatic stability.

AUTOMATIC STABILITY

As at present constituted the lateral stability of an aeroplane is largely dependent upon the aviator himself. That it is precarious at best is amply evidenced by the numerous fatalities among skilled aviators, many of which have undoubtedly resulted from inability to think quickly enough—to always do the right thing at the right moment. Control once lost is apparently lost for good, if the numerous disastrous plunges to the ground from varying heights that have followed loss of control, may be regarded as a criterion. To obtain this control by mechanical means, independent of the skill and dexterity of the aviator, is accordingly one of the most generally sought improvements in the aeroplane today.

Before describing some of the more important devices put forward to attain this end, it is essential that a clear understanding of what is meant by the term "automatic stability" be had, as it is very generally confused with "inherent stability." Any stabilizing effect brought about by the shape of the planes or the addition of keels, as represented by the numerous vertical partitions between the main planes of the first Voisin types, is merely inherent stability. This is due to the form of the machine itself, *i. e.* to the employment of extra surfaces in a certain way, so that the machine has a natural tendency to right itself and maintain an even keel in flight. This is often erroneously referred to as automatic stability, whereas the latter, in the real sense of the term, can be accomplished only by some extraneous device designed mechanically to counteract the adverse effects of the wind.

PRINCIPLES OF CONTROL

Balancing is, of course, automatic in the case of a bird and the method employed by the bird may possibly be imitated. The organs by which equilibrium is maintained are known as the semicircular canals. They are small, hair-like tubes filled with fluid lying in three planes at right angles to one another in the bone of the skull, each tube controlling through delicate nerve-ends the movements of the bird in its respective plane. Although it is not possible to reproduce artificially such a complex and delicate structure, devices designed to act in much the same manner may be employed.

Controllers employed to regulate the supplementary surfaces in this manner may be divided into three general classes: (1) Those which depend for their balancing properties upon the action of the air itself when the position of the aeroplane is altered; (2) those depending upon the action of gravity, such as pendulums; and (3) those depending upon some other force than gravity or the reaction of the air to control the balancing planes.

Air Reaction Principle. The most simple form of controller depending upon the reaction of the air is that in which longitudinal stability is regulated by an auxiliary vertical plane struck by the wind in front, and lateral stability is regulated by a plane acted upon by air currents from either side, as shown in Fig. 12. In this case, when the aeroplane turns down, the increased speed increases the pressure on the wind plane *A* and, forcing it back, elevates the horizontal rudder, or elevating plane. If it turn up, the pressure diminishes and the spring *B* brings the plane forward and depresses the rudder. If the aeroplane tilt to one side, it slides down edgewise until sufficient pressure results on the surface C to cause the latter to adjust the ailerons or warping edges of the wings to counteract this effect. The faults of this type of automatic control are obvious. Since the action of the balancing planes depends entirely upon the wind striking the controlling surfaces, the result of sudden gusts is to greatly disturb the stability of the machine. In fact, it is made much more sensitive to suddenly changing conditions than the machine which secures stable equilibrium by means of fixed supplementary surfaces as already described.

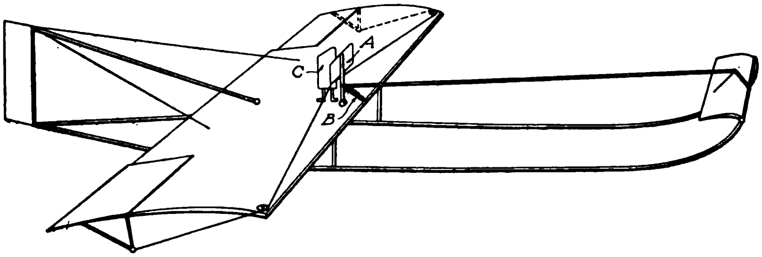

Fig. 12. Stability Control by Auxiliary Planes

Longitudinal Stability Control. To eliminate this trouble with wind gusts, the Wright Brothers invented an automatic controller of longitudinal stability designed to maintain the aeroplane flying at a definite angle of incidence instead of at a constant velocity through the air. The principle of this automatic control is shown in Fig. 13, with, however, the omission of compressed-air connections to set the horizontal rudder according to the position of the controller. The regulating plane A_1 is placed parallel to the plane of flight, and is connected by levers and rods with the elevator L. Whenever the aeroplane turns up, the wind strikes the under side of A_1 moving it to A_2 and depressing the rudder, or *vice versa*. It will be apparent that this device is likewise influenced by wind gusts but not so

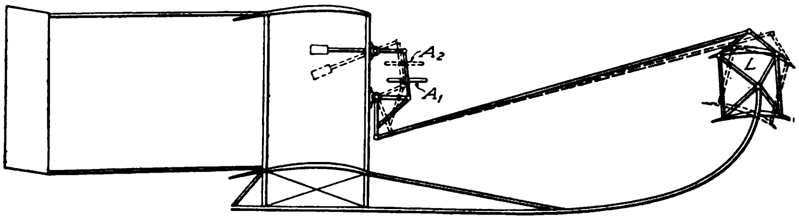

Fig. 13. Diagram of Wright Automatic Stabilizer without Compressed-Air Connections

strongly as the type just mentioned previously, though when flying close to the ground it would probably be as dangerous as the usual manual control, should the machine be suddenly struck from behind by a strong gust of wind. It has been employed in experimental flights but the Wrights state that they can not trust it as fully as they can their own skill in maintaining the equilibrium of the machine in gusty winds.

Wright Brothers' Patent. The Wright Brothers were awarded a patent in England, in 1909, on this device (No. 2913–1909). It is described as follows:

> Using compressed air or other fluid pressure as power, the action of the contrivance is controlled in one case by a pivoted vane acting under the influence of the wind; in the other case by a pendulum. In both cases the controller is merely used to operate a three-way valve, its influence upon the manipulation of the steering gear or front control (old Wright machine), as the case may be, taking place through the agency of a relay which the opening of the valve brings into action.
>
> This relay mechanism consists of a compressed-air engine which is linked up to the steering gear or front control, as the case may be, by means of a connecting rod. The engine itself is operated by compressed air from a reservoir, which would presumably be maintained or kept charged by a pump attached to the aeroplane motor. Regarding the compressed-air system as the principle, the patent covers two separate and distinct applications to the same flyer. One of these systems is exclusively devoted to the control of the elevator, *i. e.*, the front horizontal control. The other is likewise reserved solely for the manipulation of the vertical rudder and the warping of the main planes. Each of these systems has its own reservoir, or compressed-air tank, engine, and controller, the latter apparatus being, as already mentioned, a pivoted vane in the case of the elevating gear, and a pendulum in the other instance.
>
> The apparatus consists of a pulley normally under the control of the aviator through the agency of a lever, but embodies such features in its construction as enable it to be coupled up to the connecting rod of the engine which is operated from the tank of compressed air. There are two connections from this tank to the cylinder of the engine, the one to the lower part of the cylinder being permanent, while that to the upper first leads to the three-way valve designed to be operated by the automatic movements of a horizontal vane, or aeroplane, mounted on an arrangement of beams forming a parallel motion mechanism. The frame upon which these beams are pivoted hangs from brackets mounted on an adjacent part of the main struts of the flyer, and one of its members is prolonged downward to form a handle within reach of the aviator.
>
> The advantage of this arrangement is that the pilot himself may reset the course, or, as it may be better described, "the neutral line of flight;" *i. e.*, if, after having flown along a horizontal course, it is desired to ascend, the automatic mechanism may still be retained in action to guard the machine against variations from its ascending path by merely resetting the position of the frame. Since the three-way valve is mounted upon the frame and because the beams

are independently in equilibrium as a whole by reason of the balance weight, it will be evident that any alteration in the position of the frame will at once affect the state of the valve; *i.e.*, if open, it may tend to close it, or *vice versa*. Assume it to be open and the elevator set for ascent, then should the pilot wish to ascend permanently, he will move the handle so as to open the valve a little way. This will have no effect directly upon the position of the controlling vane because the balance weight serves to keep it horizontal irrespective of the position of the frame. The change from a horizontal to an ascending flight path, however, will automatically result in a change of the real altitude of the vane to the relative wind, which will now bear upon it partly from above, and will thus cause it, when the wind is strong enough, to fall a little and close the valve. This action will bring the relay mechanism into action and will alter the angle of the elevator until the conditions are restored, which will cause the controlling vane to return to its normal position. Naturally, these appliances are not dead beat and, consequently, oscillations are set up which require time to die out and it is more than likely that the normal state of affairs would be one in which the vane is constantly moving up and down.

For regulating the lateral stability, a pendulum is employed instead of a vane, the pendulum being suitably coupled to the valve so that any canting of the flyer from its normal level causes the valve to open or shut according to the requirements. The pendulum hangs straight down like a plumb bob under the influence of gravity and it is thus really the movements of the machine as a whole about the pendulum as a fixed point which form the control. In practice, the normal state of the pendulum control would presumably be one of more or less continuous, though possibly slight, oscillations. In the same way that it is possible for the vane to alter the neutral line, so can the same variation be accomplished with the pendulum, and, if necessary, the flyer be made to travel in a circular path indefinitely.

Regarding this patent, Orville Wright stated in an interview at the time of its granting:

> The device which the English are making such a fuss about is an old contrivance with which we planned to get automatic stability as long as five or six years ago. That was before anybody believed that flying as we know it today was possible. Since then we have progressed beyond this device and have others which may be great improvements. The vane and pendulum device is a very simple one. It can be adjusted to any machine in a few minutes and, theoretically, it works very well. We have used it often but I do not think it was used in connection with any big flights. Since first bringing it out, we have been working upon several devices to obtain automatic stability. We realize that if we can make an aeroplane balance automatically in the air while in flight, it will be a very important step forward.

It is accordingly apparent that a wind plane is not an entirely practical device to employ as a controller either in a horizontal or a vertical position when used in either of the ways just outlined, or in any manner partaking of the characteristics of these methods. Consequently, this eliminates all devices in that class for the time being, and the value of the pendulum, as being the chief representative of the class depending upon gravity for its action, may be considered.

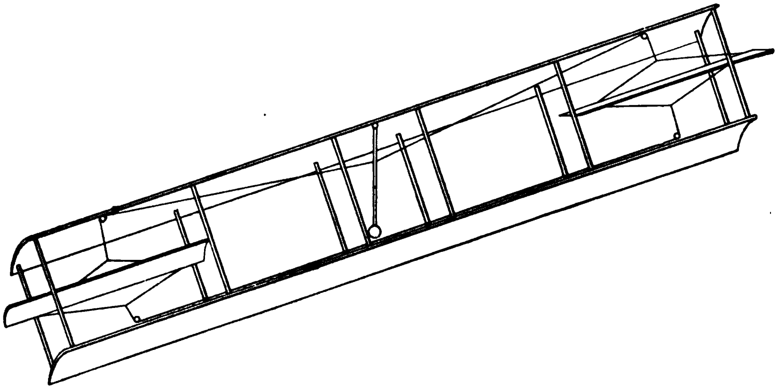

Fig. 14. Diagram Illustrating the Fault of Pendulum Control

Gravity Principle. The effect to be gained by the use of this, as illustrated in Fig. 14, is that, when the aeroplane changes its position with respect to the direction of the force of gravity, the pendulum will remain vertical, and either by direct connections or by operating valves for compressed air or by making contacts which will set electrical devices in action, it will reset the balancing planes so as to re-establish the equilibrium of the machine. This is excellent in theory and many have accepted the latter blindly, but one great difficulty is that under the influence of sudden gusts the pendulum is likely to oscillate so violently as to destroy all stability. This is not insurmountable, however, as these oscillations can be damped by friction or a water bath or a mercury level, as shown in Fig. 15. But even if these oscillations be reduced to a negligible point, the pendulum when used as a controller does not preserve a vertical position except by the reaction of the air upon the aeroplane, and, therefore, can not be successfully used. This is illustrated by Fig. 16. If the aeroplane be tipped at an angle N, there is an acceleration due to gravity tending to bring the pendulum back to a vertical position, which is evidently equal to $g \sin N$. But supposing

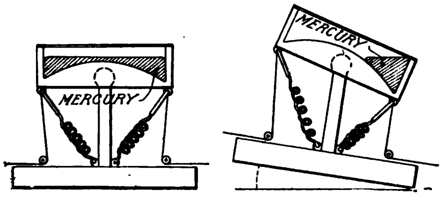

Fig. 15. Mercury Level to Dampen Oscillations

the resistance of the aeroplane to motion in a horizontal plane to be zero, when tipped at an angle of N degrees its acceleration is also $g \sin N$, the same as that of the pendulum. This being the case, there is no force to change the latter's position with reference to the former. If, however, as is always the case, the aeroplane offers some resistance to motion in a horizontal direction, as its speed through the air under the influence of gravity is increased, the resistance will increase and its acceleration will correspondingly diminish. The controller will then resume its perpendicular position and by means of its connections adjust the balance of the machine. But here the former difficulty again enters. If it is only because of the air resistance that the air controller works, it will be affected by wind currents. For instance, if a sharp gust of wind should strike the machine from one side, it would blow the wings over, while the pendulum, owing to its inertia, would tend to remain in its original position, and would therefore swing toward the wind, raising the aeroplane on that side. In fact, so many have pinned their faith to the pendulum, and still do—purely on theoretical grounds—that a resumé of the manner in which it acts under all conditions will be of value in demonstrating the futility of further attempts along this line. This, of course, refers to the use of a pendulum as a direct agency in operating the controls to give automatic stability, and not to a small pendulum employed as a relay to set a motor in operation, as in the Wright device. However, the same objections would be present in the latter device, though on a greatly reduced scale.

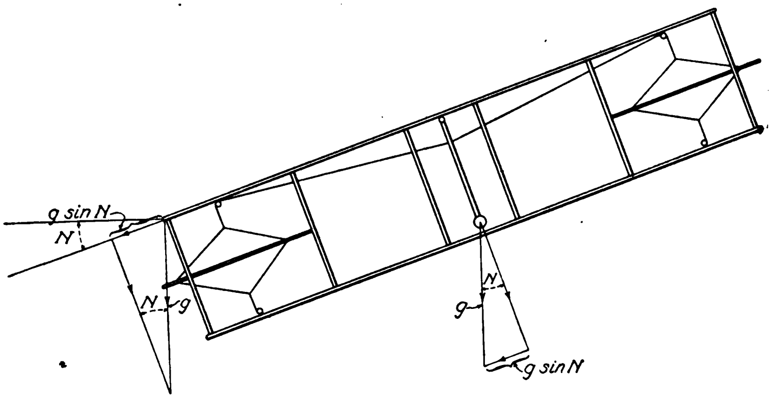

Fig. 16. Theoretical Diagram of Action of Pendulum Control

The manner in which a pendulum device is relied upon to give automatic control is best shown by reference to Figs. 17, 18, and 19. Fig. 17 represents a longitudinal section of a pendulum control *P* for fore-and-aft balance, and an elevator rudder *E*. The direction of flight is indicated by the arrow and in this same diagram the aeroplane is assumed to be in normal, horizontal flight. Fig. 18 shows the same apparatus immediately after a sudden gust has tilted the front of the machine up. The pendulum *P*, due to its inertia, has retained its vertical position *P′*, but in doing so has pulled on the rod *ab*, causing the front elevator to assume the position *E′* and to receive the pressure of the wind on its upper face. This causes a downward force on the rudder surface which brings

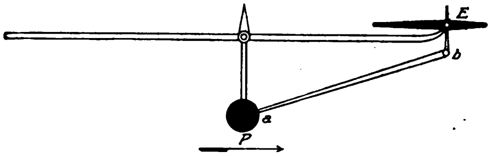

Fig. 17. Pendulum Control. Machine Going Steadily

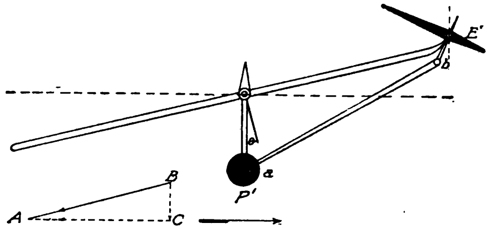

Fig. 18. Pendulum Control. Restoring Action when Machine Rears

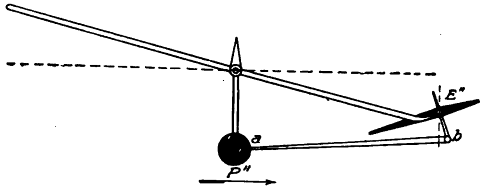

Fig. 19. Pendulum Control. Restoring Action when Machine Dips

the machine back to the horizontal. Fig. 19 represents the effect of a sudden downward plunge of the machine.

In the same manner, the inertia of the pendulum is used to move side controls when a sudden transverse tilt occurs. Of course, the nature of the pendulum and the manner in which it controls the equilibrium is vastly different in many of the suggested methods, but the fundamental principle is always the same, the pendulum itself consisting variously of an extra weight, the weight of the car, the weight of the aviator swinging on a movable seat, or the movement of a mercury bath.

Objections to Pendulum Devices. There are four distinct objections to employing any kind of a pendulum device for automatic stability:

(1) The most important objection is that, if the pendulum is at all heavy, it will tend when the machine is tilted to accentuate greatly the tipping. Thus, in Fig. 18, due to the fact that the weight P' has traveled through an angle θ, with respect to the frame, there will be a strong downward pull in the direction BA. This will certainly accentuate the downward force at the rear, due to the vertically downward component BC. If the weight is heavy enough, and the inclination great enough, this is likely to completely unbalance the machine.

(2) Another effect upon a pendulum mechanism that makes it distinctly undesirable is that if there is a sudden lurch of the entire machine, either forward or backward or to either side, unaccompanied by any tilting, then the inertia of the pendulum will cause it to swing away from the side to which the machine lurches, thus moving the rudder and actually disturbing the equilibrium of the machine, by either making it rise, plunge, or tilt over to one side. Due to "holes in the air," sudden side gusts, and even variable propeller thrusts, such sudden lurches are of more or less frequent occurrence and unless some means of deadening the pendulum is provided the equilibrium will be very unstable.

(3) The action of centrifugal force in making a turn will cause the pendulum to assume a position parallel to the struts of the machine, or of any other normally vertical parts, and it will not fly to the outside as is commonly supposed. Its action in turning, therefore, is nil, and to make the turn positive it would be necessary to

install a separate control. This arrangement assumes a proper "banking" of the machine.

(4) After any displacement of the pendulum itself from its normal position due to the sudden movement or lurch of the aeroplane, the pendulum will at once tend to swing back to the normal. If the period of this swing should just happen to coincide with the frequency of any vibration or sway in the machine or with any wave pulsations of the air stream, then the swinging would continue and be amplified, eventually destroying the equilibrium of the machine. Synchronism of this sort is not at all unlikely to happen for air waves are known to possess pulsations at regular time intervals; and in addition, propellers have often been found to give continuously and rhythmically varying thrusts, causing a slow swaying vibration in the aeroplane quite distinct from the vibration of the motor.

It appears, therefore, that the use of a pendulum for preserving the lateral stability of an aeroplane is limited in its action to the condition of comparatively steady, horizontal flight, and is hardly feasible in very gusty weather. A pendulum device, designed to act as a relay, setting in operation an electrical apparatus which causes an increase or decrease in the thrust of the screws of a four-propeller type of helicopter machine, was patented in this country as far back as 1888, and many others of a similar nature have been patented since.

All of the foregoing, however, is to a very large extent based upon the theory of the pendulum's action under the varying conditions in question, and is merely the result of the author's study of this phase of the subject from a theoretical point of view. That the conclusions reached are not well substantiated in practice will be evident from the following excerpt from a letter written by Orville Wright to the author, calling attention to the fact that his experience with the pendulum was quite to the contrary. He says:

> We have always considered a pendulum theoretically an almost perfect system for lateral balance. If the vertical rudder of a flying machine is turned so as to face the machine towards the left, the momentum or centrifugal force of the pendulum will cause it to swing to the right-hand side. This will cause the wings to be warped until the machine is banked enough to bring the pendulum at right angles to the planes, which is exactly the bank the planes should

take in making a turn. Not only is this theoretically the case, but in all of our experiments with our lateral stabilizing device this fact has been conclusively demonstrated.

There are pendulum-operated stabilizing devices in use in which it is necessary for the operator to make adjustments in order to give the machine a proper bank in turning, but this is not due to a fault of the pendulum but to other devices which have been incorporated with the pendulum in the stabilizing system. The Ellsworth lateral stabilizer is one of this type. Theoretically it would operate only in straight flight and could not make a turn without special adjustments by the operator. I have recently made some flights with a new lateral stabilizing device, in which the pendulum is used and, by simply setting the top lever of our machine slightly to one side, the device banks the machine for turning and holds it at the proper bank without any assistance from the operator. The fact that the pendulum does give a proper bank to a machine in making a turn, I consider to be its principal virtue. For theoretical reasons I have always considered gyroscopic devices inefficient for fore-and-aft control. I hold to the theory that true stabilizing devices should be dependent on the wind. Assuming a case where a machine is flying with the least power that can possibly sustain it at its most favorable angle of incidence, any device that operates purely with reference to the vertical or horizontal, will cause it to fly at a different angle in case it runs into a rising or descending trend.

I also noticed some reference to an automatic device, which I took with me and was intending to try at Kitty Hawk (October, 1911, experiments). This was an automatic device for fore-and-aft equilibrium, and is not the one described in our patent of several years ago. I did not try it on account of the presence of the newspaper men at Kitty Hawk. I have had one of the power machines here equipped with the device, and expect very soon to test it out thoroughly.

AUTOMATIC STABILIZERS

Eteve Stabilizer. A number of experiments have been made with devices designed to give automatic longitudinal stability alone, one of these—the invention of Captain Eteve, of the Sapper balloonist battalion of the French army—having been put to numerous tests in actual practice. The machine itself was a Wright biplane of French construction, the usual rear rudder of the original Wright type of machine being replaced by two hexagonal planes borne on a special stabilizer framework and controlled by spring-held cables. As shown by the sketch, Fig. 20, the two planes *A* and *B* are movable on the axis *E*, the latter being carried by a framework about 15 feet long, attached to the transverse members of the aeroplane surfaces. A horizontal vane *D*, movable on an axis *F*, is connected to the planes *A* and *B* by rods *KJ* and *KL*. The axis of the vane is firmly fixed to a tube *H*, controlled by the rod *MI* through a bell crank, *MHF*, this rod being in turn operated by a lever maneuvered by the pilot.

When the lever is fixed, axis *F* is immovable and the stabilizer vane struck by the wind moves sensibly in the belt or layer of wind immobilizing the planes *A* and *B*, which are compensated; the angle of attack of these planes is then invariable when the direction of the air current is constant, Fig. 21A. But when this latter varies, the movement of the vane is modified and the planes *A* and *B* turn in a direction contrary to that of the vane.

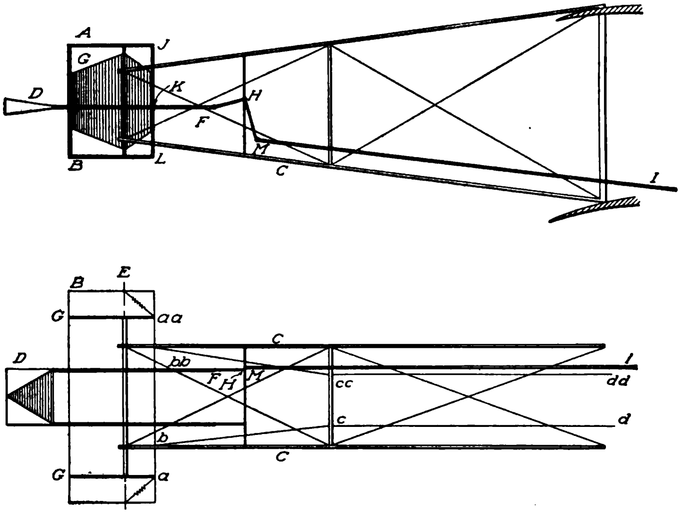

Fig. 20. Detail Diagrams of Eteve Stabilizer

Should the aeroplane "rear," Fig 21B, the vane *D* is tilted and causes the planes *A* and *B* to turn in a direction contrary to their proper movement. This tends to correct or straighten out the aeroplane; when it "plunges," Fig 21C, the reverse effect is produced and the maneuver is executed without interference owing to the simplicity of the mechanism, a quality indispensable to an automatic stabilizer. It will be noted that the Eteve device does not depend upon any external source of power but is operated by the action of the wind itself.

The planes *A* and *B*, considered as depression rudders, automatically partake of the same movements as those resulting from the maneuver made by the pilot; moreover, the vane has the advantage over the aviator of acting simultaneously with the cause that produces the disturbance of equilibrium. In a word, the Eteve stabilizer opposes all variations of the angle of attack of the aeroplane in the same manner as a very long, light, and instantaneously-acting *empennage* (tail) would. Of course, it is necessary to be able to vary the magnitude of the angle of attack in order to climb or descend. To preserve the automatic action of the stabilizer prior to, during, and after the execution of the maneuver by the pilot, the axis *F* of the vane can be raised or lowered by means of a lever under the control of the aviator, as in the Wright apparatus already described. All displacement of *F* involves a change of equilibrium of the vane and consequently a modification of the angle of attack of the planes *A* and *B*. (Note positions *D* and *E*, Fig. 21.) This indirect control of the stabilizer offers the great advantage of rendering the vane sensitive to exterior influences, the apparatus playing the role of depression rudder and stabilizer at the same time.

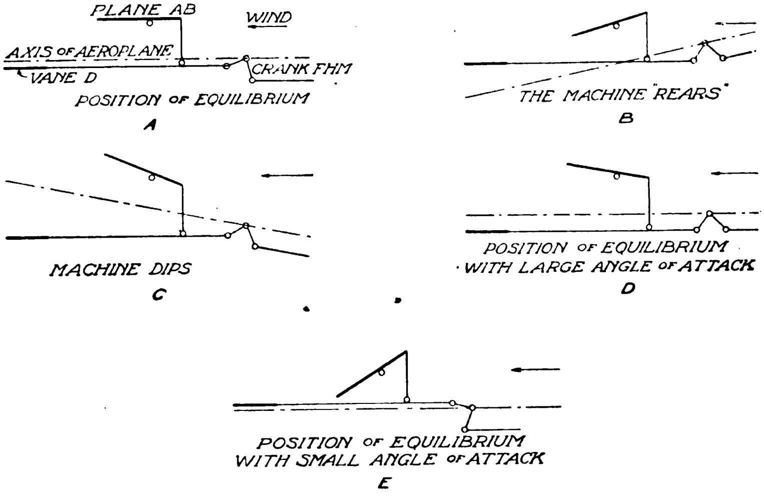

Fig. 21. Control Action of Eteve Stabilizer under Different Conditions

The weight of the entire stabilizer tail is 60.5 pounds, which, less the vertical rudder it displaces, only places an additional weight of 26.5 pounds on the machine. The total surface of the stabilizer planes is 43 square feet, or half the surface of the depression rudder of the Wright aeroplane. The numerous experimental flights made with the machine thus fitted demonstrated the important rôle played by the stabilizer. First, preliminary attempts were made to verify the equilibrium of the modified aeroplane, the operation of the apparatus then being tried out by running on the ground. Next, flights of a quarter to half a mile with turns were made; then a flight of 10 minutes was made which showed that the ordinary Wright machine can be thus readily controlled. The operation of the depression rudder was found to be considerably simplified, and despite the large surface of the depression rudder of the Wright machine, the stability was such that the apparatus frequently remained in equilibrium for some minutes without the intervention of the aviator.

Gyroscopic Stabilizers. The consideration of the different types of automatic controllers already discussed leads to a conclusion which is almost self-evident. The same cause always produces the same result and hence, when an aeroplane is tipped to one side, if it is turned back to its proper level by the action of the air due to its change of velocity or angle of flight through the air in that direction, then, when an equal change in angle of flight or speed through the air is caused by some gust striking the machine, the aeroplane will be affected in a similar manner. For instance, when an aeroplane in stable equilibrium turns upward, its speed through the air is diminished and the front drops to the proper level, but when a wind strikes it from behind, its speed through the air is likewise diminished and the front will again drop, but this time away from the proper angle of flight. Therefore, since it is found that the stability of all machines balanced in a manner similar to those above described must depend upon the machine's reaction with the air, no such system of automatic equilibrium can be depended upon to preserve perfect balance while the aeroplane sails through the currents and cross currents met with in practically every flight.

True Stabilizer Independent of Wind Changes. It is essential, therefore, that the controller shall be sensitive not to the force or direction of the wind that strikes the machine, but to some other force which will move the controller with respect to the aeroplane when its equilibrium is disturbed. The only such forces known are that of the earth's magnetic field acting on a magnetic needle, and the gyroscopic force of a rapidly rotating wheel. The magnetic needle is usually employed merely to indicate the north, but since the earth's magnetic field tends to make it dip downward at an angle of about 75 degrees with the horizon, and since this angle is constant in any locality, if the direction of flight be fixed, the magnet may be employed to determine a horizontal position. It may be made to operate the controlling planes through the medium of electromagnets acting to open and close the valves of a compressed-air motor. Since both arms of the magnet have the same mass, neither gravity nor centrifugal force, due to the oscillations of the aeroplane, would affect it in any way, but the slightest vibration once started would continue indefinitely and thus be transmitted to the control of the aeroplane. Also in making turns, since the needle points downward at an angle of 75 degrees, instead of 90 degrees, there would be danger of losing balance. So, aside from the prohibitive frailness of the construction, the magnetic needle would not make a suitable controlling device. It is therefore necessary to examine what can be accomplished with the aid of the gyroscope.

Gyroscopic Action. It is a well-known fact that a rapidly spinning top forcibly resists any attempt to change its plane of rotation. This force depends upon the weight at the periphery of the revolving body and its speed of rotation. The top is a gyroscope in its simplest form, and by giving it the form of a flywheel with a heavy rim we have the toy that is doubtless familiar to most boys—the gyroscopic top. In this, the diminutive flywheel is supported on a spindle carried in a circle of wire in order to provide a means of support independent of the spindle itself. When spinning rapidly, such a top will continue to rotate in any plane in which it is placed, horizontally, vertically, or at any angle between the two. This singularly curious force was first applied industrially in 1870. Since then the progress achieved in its use has been comparatively slow. It has been employed for securing much-needed stability to the Beauchamp hydraulic turret, the Obry torpedo, the Scherl, Brennan, and Froelich monorail systems of transportation, and to Schlick's device for preventing the rolling of a ship.

Widespread interest now attaches to its employment in a similar rôle on the aeroplane. In this connection, however, the distinction between equilibrium and stability should be borne in mind as the terms are so frequently used interchangeably as to prove confusing.

Briefly stated, an aeroplane is in equilibrium when traveling at a uniform rate of speed, and it is necessary for stability that, if the aeroplane is not in equilibrium and be not moving uniformly, it shall tend toward a center of equilibrium, also that any oscillatory motion shall have a positive coefficient of subsidence. A thorough study of the different forms of machines made by a close observer led him to the conclusion that the only two types likely to prove stable under ordinary conditions are the single-surface glider and the balanced glider. The first, as he expressed it, relies for its longitudinal stability on the variation of the center of pressure with the angle of attack, while the second relies on the variation in altitude of a balancer or tail surface. In each case, a torque should come into existence to bring the glider back to its original position. With these types, however, as they now stand, a very severe squall is likely to prove disastrous; for the righting of the machine can not be made rapidly enough. There must necessarily be an automatic adjustment to secure the equilibrium of all the planes.

Regnard Device. To bring about this automatic adjustment, numerous inventors are looking to the gyroscope as a solution of the problem, one of the first machines to be equipped with it being the Regnard monoplane. The details of the aeroplane in plan and elevation are shown in Fig. 22, while the gyroscope and its mounting are given in Fig. 23. In this case, the small and comparatively light gyroscope used is not directly employed to insure stability. It merely serves to transmit an electrical current to devices for giving both lateral and longitudinal stability. The gyroscope itself, *A*, Fig. 22, is located directly beneath the center of the main supporting surface *I* and in line with the motor. It is hung on gimbals—*i.e.*, a universally-jointed support, Fig. 23, permitting complete independence and freedom of movement. Within the ring *A* of this gyroscope is the flywheel *T* and the ring armature *C* of a small electric motor to which it is directly coupled at its lower end.

The stationary field *L* of the motor is also of the ring type and lies in the same plane as the armature it encloses. Current from eight or ten storage cells of about the size ordinarily employed in electric vehicles, maintains the flywheel in rotation at a speed of 10,000 r. p. m. According to well-known laws of mechanics, it will adopt under the influence of this rotative speed an invariable plane, parallel to the plane of the space wherein it is hung—a horizontal plane in this case. Owing to its method of support it will take, with reference to the aeroplane, all the relative positions corresponding to the inclination of the latter. In other words, the gyroscope will continue to revolve in its horizontal plane, while its frame, attached to the aeroplane, will assume different positions relative to it in accordance with the angle of inclination of the machine, *i.e.*, the gyroscope remains stationary while its support moves about it as a fixed

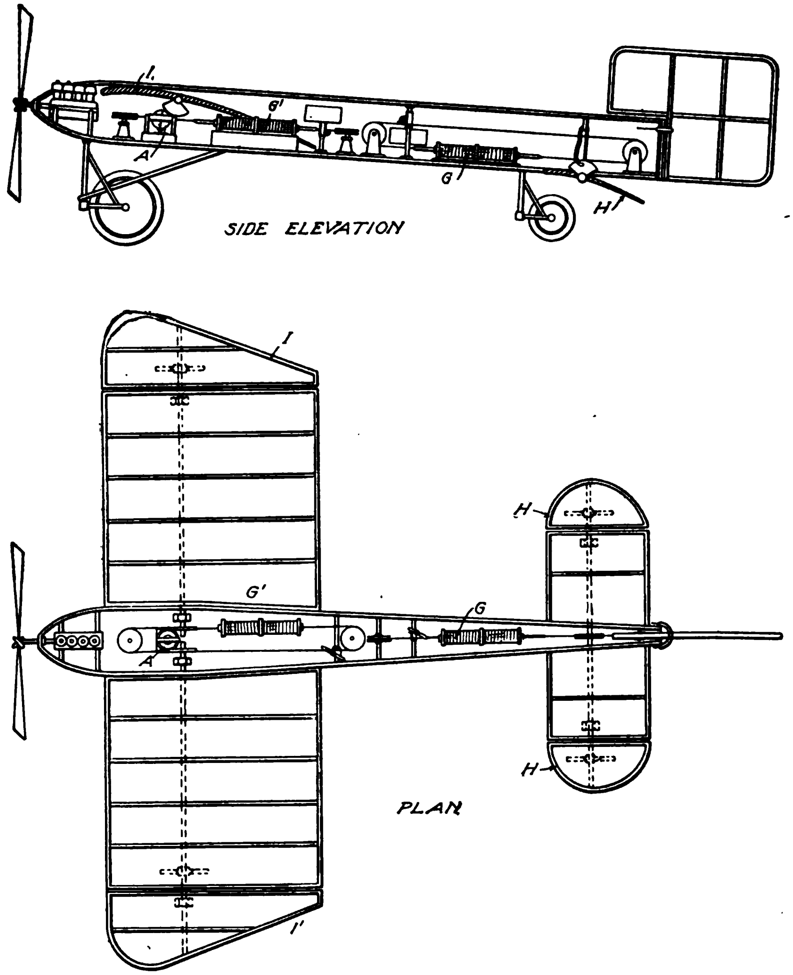

Fig. 22. Detail Diagrams of Regnard Gyroscopic Stabiliser

point. In doing so, the stud *E*, rigidly attached to the gyroscope, establishes electric contact with the plates *F*, according to the movements of the aeroplane. Each of these contacts is alternately employed for controlling and steadying the movements of one or more of the surfaces of the aeroplane.

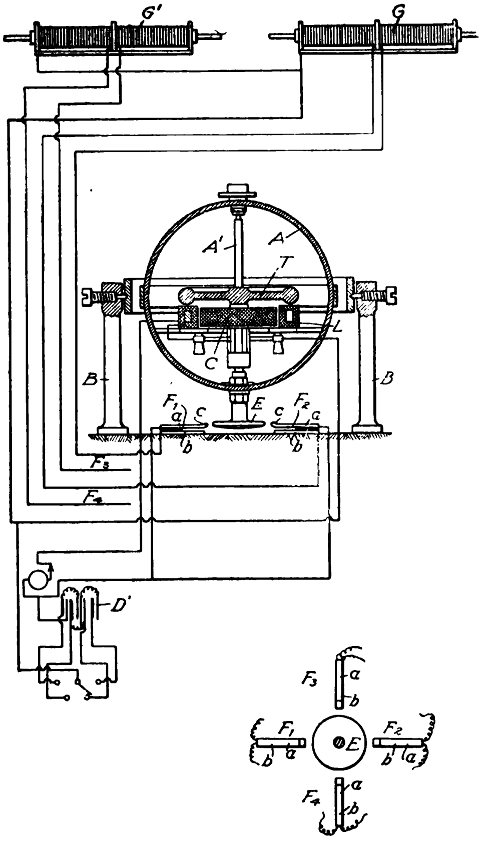

Fig. 23. Gyroscopic Control-Device of Regnard Stabilizer

These contacts can be made in a number of different ways—by way of example, as shown in the upper and lower diagrams of Fig. 23, through the medium of the conducting plates *a* and *b*, which are superposed but not touching. The upper plate *a* has a projection *c* on which the stud *E* will press, the convex surface of the latter always corresponding to the center of rotation of the gyroscope. Regardless of the inclination of the aeroplane the axis of *E* is always vertical, and in whatever direction the machine cants, it will press momentarily upon the plate *a*, the latter then coming in contact with *b*. The circuit thus established can be utilized for specially controlling any one or more of the balancing organs of the aeroplane. In the present instance, this is effected by means of solenoids, or hollow electromagnets, in which soft iron plungers slide. Two of these solenoids, *G* and *G'*, are employed, adapted to be energized in alternate directions by means of two sets of contacts, F_1 and F_2, for the longitudinal balance, and F_3 and

F_4 for the lateral balance. For instance, should a strong gust of wind cause the aeroplane to tilt downward, E will instantly make contact with F_1, energizing the solenoid G. The plunger of the latter is suitably connected by means of a cable to the elevating rudder H and the pull exerted by the solenoid will vary its angle of attack downward, thus righting the machine, or bringing it to an even keel. In case of the reverse inclination—the tendency of the aeroplane to stand on its tail—the solenoid G will again come into action through the contact F_2, but the plunger will move in the other direction due to a reversal of the current, and the elevating rudder will be moved to the opposite angle, again bringing the machine down to an even keel, or horizontal plane. Transverse control is maintained in a similar manner, an inclination to either side causing the solenoid G' to come into action in one direction or the other through the contacts F_3 and F_4, according to the movement of the aeroplane itself. The plunger of this solenoid is connected through suitable multiplying gear and cables to the warping apparatus of the wings.

It will be noted that this device is practically similar in its operation to the Wright apparatus, except that a gyroscope is employed as an automatic governing control in place of the vane and pendulum of the latter, and electric power is employed instead of compressed air. In other words, both devices merely relieve the aviator of the constant necessity of manually operating the usual controls for maintaining longitudinal and lateral stability—the elevating rudder and the wing-warping levers. There is nothing unusual about the Regnard apparatus electrically or mechanically, except the automatic method of making contact by means of the gyroscope, the action of a solenoid being commonly utilized to operate such electrical apparatus as circuit breakers and the like. However, the efficiency of a solenoid is comparatively low; it requires considerable current to cause it to generate an appreciable amount of power and to act quickly. With such a limited source of power as the storage cells mentioned, the solenoids would have to be prohibitively heavy. Of course, a dynamo could be run by the motor of the aeroplane itself, but this likewise involves considerable extra weight. Moreover, while an apparatus such as that described would be considered simple for an electric lighting station or similar installation, it involves an excessive amount of complication for an aeroplane—there would be entirely too many small things to look after and keep in order. Using a generator directly attached to the gasoline motor and two small electric motors instead of the solenoids, would simplify the apparatus somewhat and make it much more powerful for its weight, but still there would be entirely too much unnecessary weight to carry along. The attempt is interesting as illustrating what may be done, but there are doubtless few aviators who would not prefer to rely upon their skill in manually operating the controls rather than have the machine encumbered with so much apparatus, particularly as some means of cutting out its action when desiring to ascend or descend would also have to be provided, as mentioned in connection with both the Wright and Eteve stabilizing devices.

Beach Device. Utilizing the controlling force of the gyroscope direct would appear to hold forth much greater promise of simplicity and reliability in action. This was attempted during 1910 by an American, Stanley Y. Beach, the aeronautical editor of the *Scientific American.* The gyroscope in this case is a flywheel weighing about 20 pounds and is designed to revolve in a vacuum at 10,000 r.p.m. The complete apparatus weighs about 30 pounds. The gyroscope itself is illustrated in Fig. 24, while its location and method of attachment to a Beach monoplane (Bleriot type) is shown at the bottom of Fig. 25. The flywheel is driven through bevel gears so that it runs about three times as fast as the driving pulley on the horizontal shaft. The spindle projecting out at the top, Fig. 24, passes down through a long bushing about 6 inches in length and drives a short shaft at the bottom through a ratchet attachment. It is in fact, a friction drive, the details of which are not as yet protected by patents, for which reason they are not given here.

To obtain the vacuum, which makes necessary only a fraction of a horse-power to drive the flywheel, a small vacuum pump, about the size of the ordinary bicycle pump, is attached by means of a short rubber tube to a pet cock at the apex of the conical housing. The air can be exhausted from this housing with the pump in question in about five minutes, and the leakage about the stuffing box of the spindle is so slight that the vacuum is maintained for almost twenty-four hours. The only object of employing a vacuum is to minimize the amount of driving power necessary, it having no effect one way or the other upon the gyroscope or its action. When driven in the air, two or three times as much power is required and it takes a great deal longer to get the flywheel up to speed owing to the resistance. With a vacuum, on the other hand, only about fifteen minutes are necessary for it to attain a speed of 10,000 r.p.m. and it will then continue to run for one and a half to two hours without any further application of power.

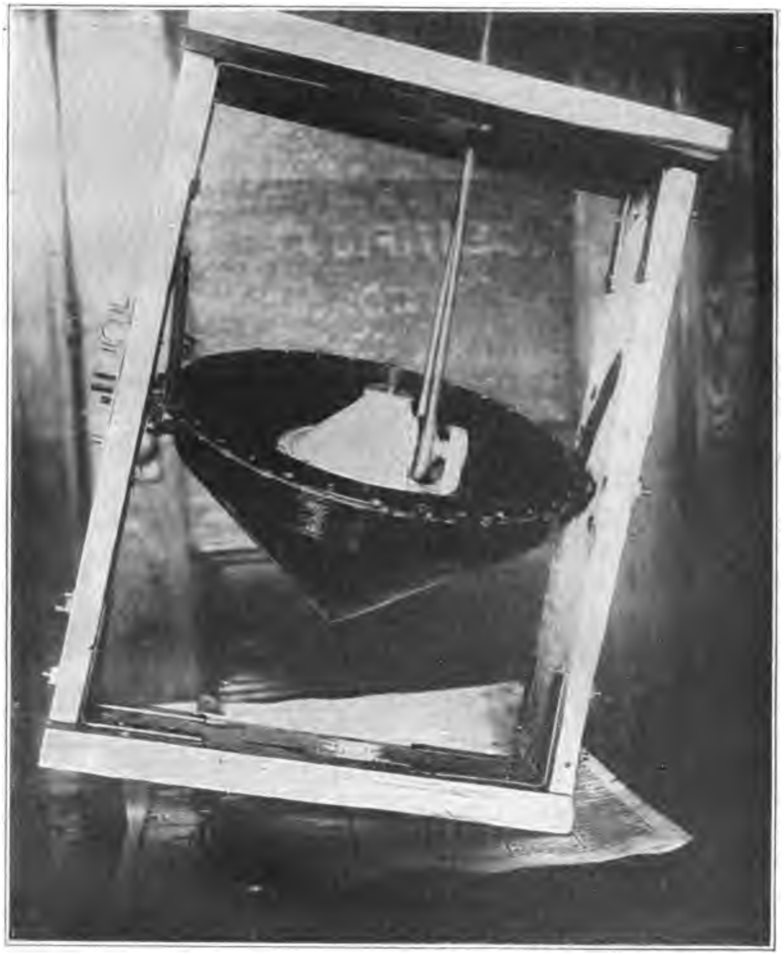

Fig. 24. Beach Gyroscopic Stabilizer

When the aeroplane tends to tilt to either side, the gyroscope will resist this inclination with a force of 900 pounds at a distance of 1 foot from the center of the flywheel. At the same time, as the aeroplane inclines slightly to one side or the other, the gyroscope will tilt forward or backward, as the case may be. To permit of overcoming this force of the gyroscope, when not desired, a band brake acting on a drum on the shaft (not shown in the illustration) is employed. This locks the gyroscope and prevents its performing its act of *precession*, as it is technically termed. In this condition its resistance is practically negligible and applying this brake allows the aeroplane to "bank" in rounding a turn by means of the transverse warping control as is customarily done. Should the aviator neglect to apply this brake before attempting to make a turn, however, no harm will result, as the machine will then simply remain on a level keel and "skid" or slide toward the outer circumference of the curve it is making, under the action of centrifugal force. Fig. 24 shows the complete gyroscope mounted in a frame corresponding to its support on the aeroplane, this frame being tipped to represent the inclination of the flyer to the right. It is being driven at its usual high speed as shown here and the forward *tilt of the apparatus* is noticeable, though this does not appear to

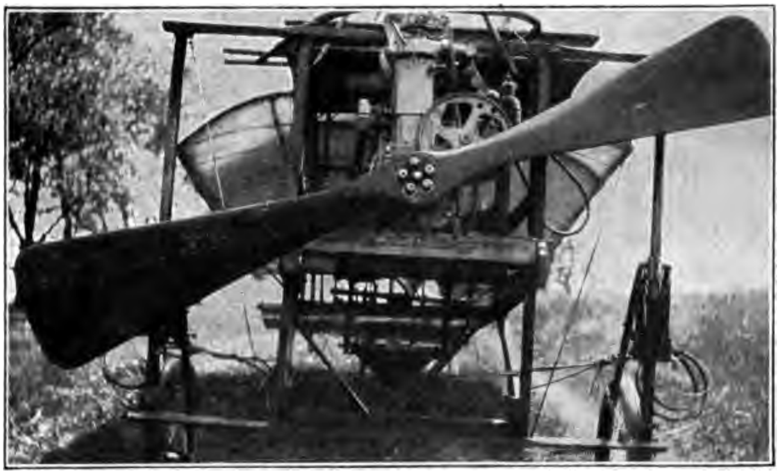

Fig. 25. Beach Gyroscopic Stabilizer Mounted in an Aeroplane Frame

be as great as it is in reality. When tried on a monoplane running over the ground, this gyroscope gave a perceptibly steadying effect, though not running at more than half its normal speed.

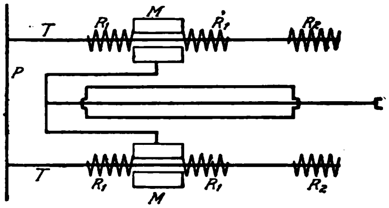

Fig. 26. Diagram of Doutre Stabiliser

Doutre Stabilizer. This is a type that differs more or less radically from any of those already mentioned. It has been put to severe tests by the army in both France and Russia and has showed unusually promising results. The apparatus consists of two elements, each fulfilling a distinct function. The first of these is, properly speaking, an anemometer whose purpose is to detect changes in the wind pressure; the second element constitutes an accelerometer, its function being to detect and respond to changes in the velocity of the aeroplane. These two elements are so arranged as to act either separately or jointly, according to exigencies, upon the mechanism controlling the elevating rudder at the front of the aeroplane. The anemometer, which is shown in diagrammatical representation in Fig. 26 and in greater detail in Fig. 27, comprises a plate *P*, mounted on four rods *T*, connected with two tubes *A* which slide smoothly in an aluminum body *S*. Springs R_2 oppose the tendency of the air to force back the plate *P*, when the latter is moving in a direction from left to right. The strength of the springs is so adjusted that when the relative wind pressure is equal to or greater than that required to sustain the aeroplane, the springs R_2 are compressed to their limit and the tubes *A* thrust back against a shoulder upon the aluminum casing. If the pressure of the wind falls below this value, the springs R_1 act on the weights *M*, which in turn, through the pins *O*, thrust forward the rods *E*. These latter rods are rigidly connected with the sliding piston rod *N* of an auxiliary motor, the cylinder *C* of which receives through the chamber *D* compressed air acting upon the piston B_1. There is no need to enter into detailed description of the auxiliary motor, the principle of which is well known; air is admitted into the compartments *H* and *I*, according as the displacement of the piston rod *N* opens or closes the admission port shown in dotted lines. The surplus air escapes through openings at the end of the rod *N*, or the piston B_1, as the case may be. Every displacement of *N* is immediately followed, in consequence of the arrangement described, by a displacement in the same direction of the piston B_1. This latter actuates the rudder through a pivoted point B_2.

So far the control of the rod *N* by the springs R_2 has been described. But there is a second control, which is effected by the two weights *M*. These are ordinarily kept stationary by the springs R_1. But if the aeroplane makes a sudden plunge, the inertia of the weights causes them to lag behind the motion of the body of the machine; thus there is a relative motion of the weights *M* in regard to the tubes *A* upon which they slide, a motion which is directed either forward or backward according as the acceleration of the machine is negative or positive. These movements of the weights are transmitted to the rods *E* by the pins *O*, and thus react on *N* and the auxiliary motor much in the same way as the plate *P*. A force of 100 grams weight (3.2 ounces) is sufficient to affect the apparatus, while the auxiliary motor, which receives its air supply from the aeroplane motor, readily gives a thrust of 10 to 30 kilograms (22 to 66 pounds). This is more than sufficient to operate the rudder.

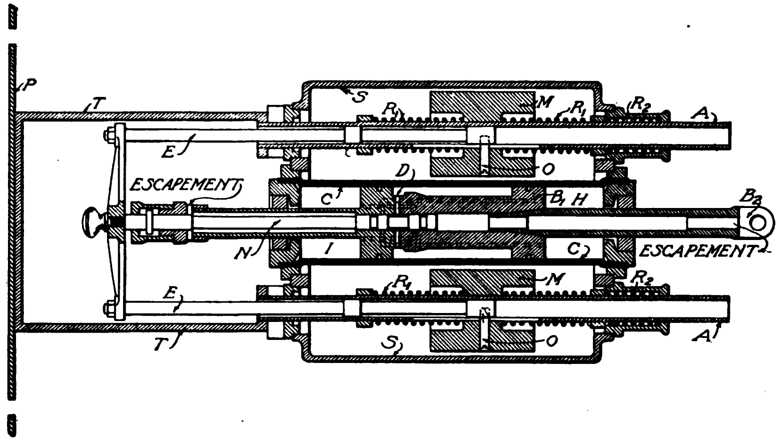

Fig. 27. Detail Section of Doutre Stabilizer

The anemometer plate and the accelerometer weights both act independently and simultaneously upon the elevating rudder. Their effect is either added or opposed, according to the conditions of flight, and the whole is adjusted so as to give the proper steering upon the rudder. Since each variation in the angle of the rudder brings about a variation in the aeroplane speed, the apparatus acts to correct the effect of its own action on the rudder, even while this is taking place. It is also to be noted that the apparatus does not wait to act until the aeroplane has taken a false movement, but it acts directly under the shock which also tends to act upon the aeroplane, thus taking account of the cause itself and not the effect. The correction given to the rudder is thus very quick. The movement of the main rod of the apparatus is transmitted to the rudder in a very simple way by the use of compressed air, the air being furnished by a small compressor driven from the aeroplane motor itself. The compressed air piston device is operated by the main rod, and the piston movement is transmitted in a suitable way to the rudder, independent of the pilot's levers. The pilot can work the rudder himself or he can remove his hands from the levers and allow the automatic device to do the steering, at least for a short time.

Trials of the Doutre stabilizer have shown it to be so sensitive in action that the pilot has removed his hands from the levers while the machine was still rolling on the ground, and the automatic apparatus has assumed control of the aeroplane causing it to rise, the operator again taking hold after reaching an elevation of 60 feet. The aeroplane was then sent up to a height of 1,000 feet, and again entrusted to the stabilizer, the pilot keeping his hands on the levers, but not working them. It was noted that the small plate kept up a slight beating movement, working back and forth over some three inches, as an indicating pointer showed; the rudder followed up this slight movement, so that the flight was very steady. The levers moved somewhat under the action of the apparatus, despite the fact that the pilot kept his hands on them. He then raised his hands for periods of four to six seconds, resuming them only to take care of the side steering to avoid a rolling movement. At times it was quite evident that no effort was required, the automatic device doing all the steering. When the pilot tried to oppose the action of the stabilizer he had to use quite a little force. At one time, the apparatus was left to itself entirely for twelve seconds; then the pilot slowed up the motor several times, and each time the plate and the moving weights gave the right action to the rudder.

Returning, the motor was slowed up and the aeroplane descended on a very good slope and the apparatus always corrected the descent so that it took place under the best conditions right to the moment of landing. The action is shown diagrammatically in Figs. 28, 29, and 30. The test was thus very conclusive, and numerous others made subsequently proved equally satisfactory. Three aeroplanes for the French army have been fitted with the Doutre apparatus.

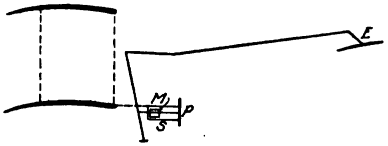

Fig. 28. Doutre Stabilizer. Action of *M* on Sudden Acceleration

Ellsworth Lateral Stabilizer. Supplementing the good results obtained with the French longitudinal stabilizer just described is an American device for maintaining lateral stability, which after all is quite as important, if not more so. As a general rule a properly-designed aeroplane is well balanced longitudinally and does not ordinarily tend to pitch, while its lateral stability is a matter that has to be corrected every few minutes during the entire flight. The device is the invention of a resident of Portland, Oregon, and is the first lateral automatic stabilizer to be successfully tried out in practice. The mechanism consists of two rotating electromagnets driven in opposite directions by a gear. An armature between these two multipolar magnets is keyed to a shaft carrying a drum so that any movement of the armature carries the drum with it. This drum carries cables connected to the ailerons or wing tips for balancing. An electric circuit is completed by an arm of a pendulum dipping into a mercury cup upon the listing of the aeroplane to either side. One of the rotating magnets is then excited and exerts a magnetic pull on the armature, thus rotating the drum. The drum shaft, however, terminates in a gear, and the block containing the mercury contact

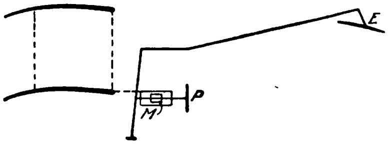

Fig. 29. Plate *P* Sets Elevating Rudder for Descent if Speed Slackens

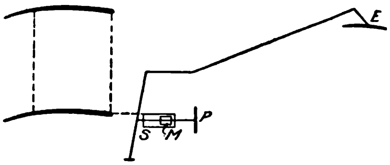

Fig. 30. Motor Breakdown Sets Rudder for Volplaning

cup is so attached to the gear wheel that the rotation of the latter will drop the cup away from the pendulum arm, again breaking the circuit and leaving the ailerons set to right the aeroplane. As the latter resumes its normal level of flight, the action of the stabilizer is reversed, returning the ailerons to their normal neutral position. Means are provided which permit the aviator to rotate the block containing the mercury cups at will, thus making contact for banking the aeroplane to any required angle to round a curve. A movement of the block does not cause any movement of the gear wheel, yet a movement of the latter causes a relative movement of the block. This permits the aviator to alter his angles laterally, of course, at will without in any way interfering with the automatic control. It can be applied to fore and aft, as well as lateral, control. One of the Ellsworth stabilizers was fitted to a Curtiss biplane during the fall of 1911, and, in the course of an extended series of flights, it was said to respond instantly to the least variation from the horizontal far more quickly than could be detected by the aviator himself. This was learned by having the wires from the ailerons connected to the steering post, which was pulled from side to side by the action of the automatic control in maintaining the balance, before the aviator was even aware that the balance had been sufficiently disturbed to make this necessary. In turning corners, the stabilizer banks the aeroplane automatically by having the mechanism connected to and controlled by the steering wheel, thereby banking the machine at just the required angle for the turn; but the amount of this banking is always at the instant command of the aviator should he desire to make it more or less, and the automatic balance is not interfered with in any way. The device is very compact, weighing but 18 pounds, and is adapted to be driven directly from the aeroplane motor, but it can also be arranged so as to be driven from an electric motor and storage batteries to provide against stoppage of the driving motor, in which case the drive would automatically be taken up by the electric motor. This addition, however, would involve extra complication and weight that ordinarily would not be considered justifiable.

While many investigators are working on the problem of automatic stability as revealed by the various devices described here, opinion as to the necessity of providing any automatic form of control is more or less divided at the present writing. It seems probable, however, that the perfected machine of the future will embody this feature, and that it will be of such a flexible character as to permit manual control of the machine at all times and yet be capable of preventing such complete loss of equilibrium as seems to have occurred in the cases of Moisant, Hoxsey, and Johnstone—in other words, a self-righting ability analogous to and approaching as closely as possible to that shown by the birds when accidentally capsized in violent winds. Hoxsey's death, for example, which is generally thought to have been due to loss of consciousness resulting from the sudden change of altitude, might have been averted by such a device as it would have brought the machine to the ground without damage.

ALTITUDE AND ITS MEASUREMENT

Nothing more strikingly reveals the great development of the aeroplane in a very short time and the absolute command over it that has been achieved, than the rapidity with which altitude records have followed one another. It will be recalled that the pioneers of aerial flight had quite as much difficulty in learning to fly as they did in designing a machine in which to accomplish it, and they trusted themselves to a motor-driven craft only after having thoroughly mastered the principles of the art through long-repeated practice in gliding. There was, therefore, nothing strange in the fact that although flight in a heavier-than-air machine was actually a reality, the flyers preferred at first to remain close to the ground. For this reason there was keen and widespread disappointment among the spectators who attended the first public exhibitions of flying in this country by Farman, the Frenchman. The manner in which he kept close to the ground, never exceeding a height of 50 feet and oftener remaining within 30, was not at all satisfactory to the crowd to whom the definition of the word *flying* did not mean the ground-skimming swoops of the sparrow, but the lofty soaring of the eagle or larger birds. From a spectacular point of view, Farman's exhibition was an utter failure.

Altitude Records. With increasing confidence, heights of 200 or 300 feet were attained and at some of the earlier French meetings the height reached by the aviator was determined by means of a captive balloon anchored over the field. If the contestant flew above it, he surpassed the former record and there was not much question of definite figures. But advancement was so rapid that this plan very soon became obsolete. From the few hundred feet that seemed to mark the limit in the early part of 1908, Morane rose to 2,500 meters or 8,202 feet but little more than a year later, September 3, 1909. This eye-opening performance showed what could be done and immediately inspired confidence in others. Competition was fostered by numerous and substantial prizes offered for altitude at meetings, and one record followed another, Johnstone reaching a height of 9,714 feet in a Wright biplane during the International Meet at Belmont Park in October, 1910, and Drexel surpassing this in a Bleriot monoplane only a few weeks later at Philadelphia by attaining an altitude of 9,897 feet. As this record stood but little more than a month before being raised by the very liberal margin of more than 1,000 feet by Hoxsey who soared to an altitude of 11,474 feet in California on December 27, 1910, it is quite apparent that a point has already been reached where the matter of soaring is one limited only by human rather than mechanical shortcomings. In other words, it seems quite possible that an aeroplane can be flown as high as human endurance will permit. The various elevations attained by human effort are shown in Fig. 31.*

It has been a matter of common knowledge for many years that ascending to great heights on mountains is attended by considerable physical discomfort and is accompanied by disagreeable physiological symptoms. Some individuals are peculiarly susceptible to the latter and claim to be affected by them at an elevation of only a few thousand feet. While mountain climbing offers some analogy to aeroplane climbing, the gradual transition from the heavier to the lighter and more rarefied atmosphere permits ample opportunity for the body to accustom itself to the change. In contrast with this, it has been common for aviators to travel the first 7,000 or 8,000 feet of their record-breaking upward flights in a little more or less than half an hour. Hoxsey is said to have risen the first 9,000 feet of his record flight in California in thirty-five minutes. This is equivalent to being transported upward a mile and three-quarters in about the

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*These were considerably surpassed in 1911, Beachey having risen well over 12,000 feet at the Chicago Meet in August, while French aviators have also been making new altitude records.—Ed.

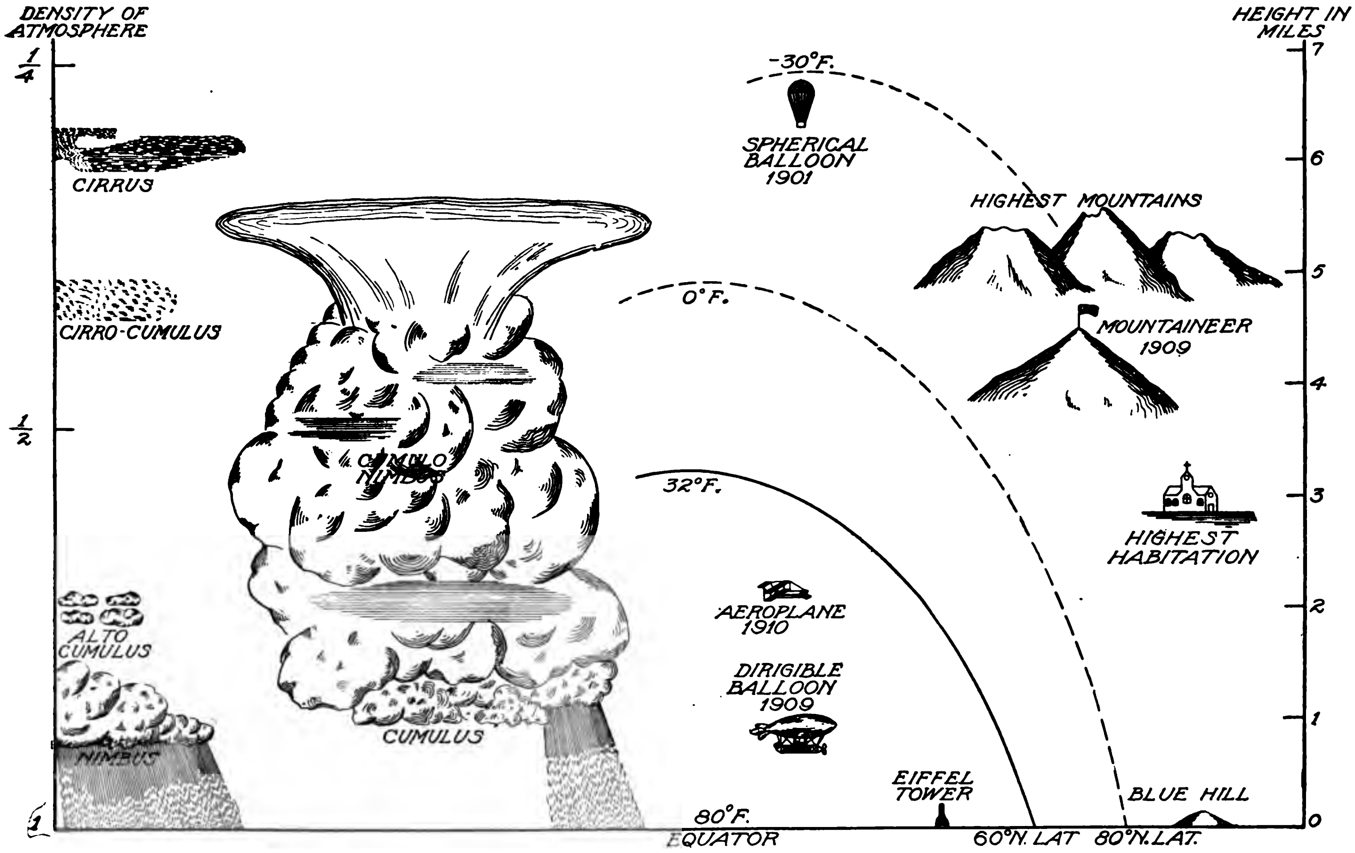

Fig. 31. Heights Attained by Man through Various Agencies

same time that it would take the express elevators of one of our sky-scraping towers to make the same distance. The barograph record of Hoxsey's flight at Belmont, Park October 27, 1910, Fig. 32, shows that he rose to a height of over 5,000 feet in the first thirty minutes. In this flight, however, he found the wind too severe and reached an elevation of only 6,500 feet; in attempting to get down, he dropped the whole distance in less than fifteen minutes, having been blown backward about 30 miles. Fig. 33 shows the record made at the same time and place by Johnstone when, although facing the wind, he was blown backward 42 miles. It is well known that the sudden transition from the high pressure of a subaqueous tunnel or foundation caisson to the normal sea-level atmosphere is often attended with fatal results, and it does not seem unlikely that the reverse process of going from a comparatively low pressure to a much higher one in a short time, as where the aviator descends from a height of 9,000 to 10,000 feet in less than 10 minutes, physical inconvenience might follow. Experiments carried out by prominent physicians in France show that such an experience is attended by a considerable increase in the blood pressure of the individual. The time of transition is so short that the circulatory system does not have time to adapt itself to the change in pressure.

The aviator, after a quick descent from anything above a few thousand feet, suffers from headache, ringing in the ears, and a high pulse, and his feet and hands are apt to be blue and numb—quite as much from impeded circulation as from the cold experienced at a great height. These experiments invariably showed that the blood pressure was increased as much as 30 to 40 per cent, despite the fact that the aviators in every case were trained athletes in full form. The rise in temperature was less apparent where the individual was fatigued, and was not present where the flight did not exceed a height of 300 or 400 feet. By the result of these experiments, the importance of descending slowly is pointed out, as well as the dangerous fatigue to which flight at high altitudes exposes the circulatory apparatus by provoking increased and irregular activity of the heart. That some of the fatalities ascribed to mechanical defects might in reality have been due to fatigue of the human machine, seems quite possible.

Methods of Altitude Measurement. *Captive Balloon.* Interest in high flying and altitude records is so general that a description of

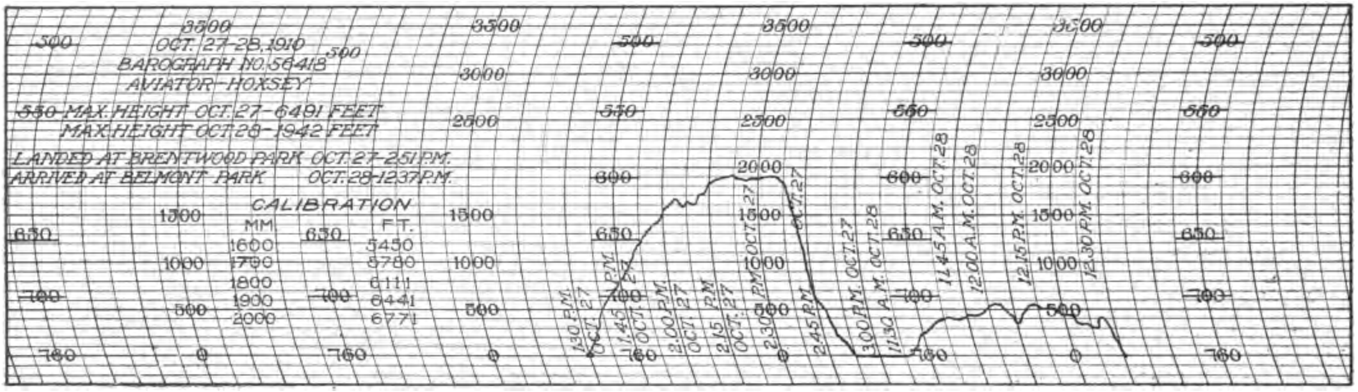

Fig. 32. Barograph Record of Hoxsey's Flight at Belmont Park, October, 1910

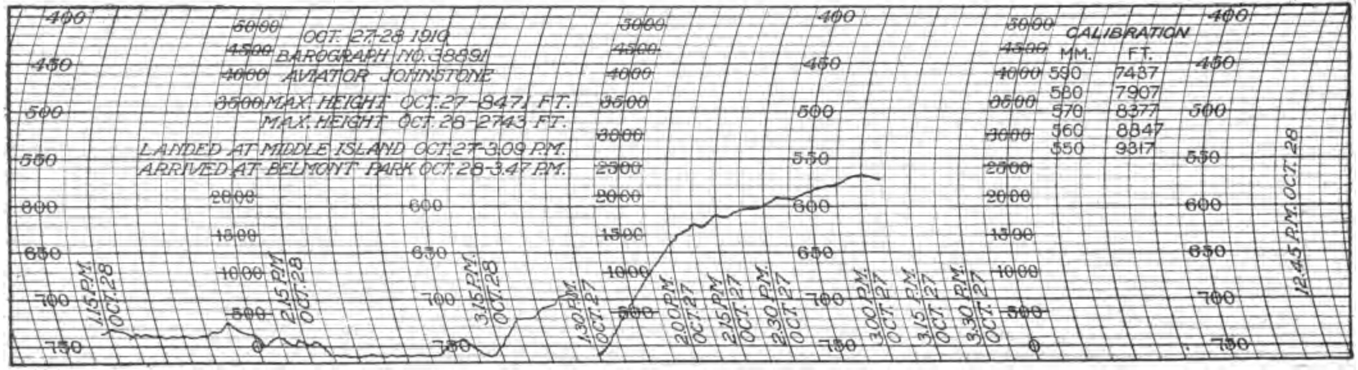

Fig. 33. Barograph Record of Johnstone's Flight at Belmont Park, October, 1910

the methods employed in ascertaining the height reached by an aviator will be appropriate here. There are numerous ways of measuring elevation—of varying degrees of accuracy—and in general the simplest and easiest are the least accurate. When a record is to be made, possibly exceeding a rival's by a few feet only, exactness is evidently a desideratum. In view of the conditions, however, it is naturally out of the question to reduce matters to such a fine point as this. A rule has accordingly been adopted recently by the Aero Club that henceforth an altitude flight is to be considered as making a record only when it exceeds by at least 300 feet the mark previously set. In 1908, getting up as much as 300 feet was in itself considered a record. At that time a certain amount of rope with a captive balloon attached to its upper end sufficed as a measure of the height reached. The fact that a calm might permit the balloon to rise straight up and stay there or a wind might carry it along some distance thus reducing its vertical height above the ground considerably made little difference. As a matter of fact, a breeze sufficient to do this was more than enough to prevent a flight of any kind.

Triangulation. The balloon very shortly becoming of no further use as an altitude indicator, triangulation was resorted to, this method being employed at the Harvard Meet near Boston, in September, 1910. By this means, two observers at the end of a measured base line watch the soaring machine and obtain its angle of elevation simultaneously. From these two angles and the length of the base the other two sides of the triangle, and, consequently, the height of its apex, may readily be calculated with the aid of trigonometric formulas. The longer the base line adopted and the more accurate the instruments employed for the observation, the more exact the result will be. The preparations for checking the heights reached by the aviators at the Harvard Meet were the most elaborate ever undertaken in this country.

It was assumed that a height of 10,000 feet might be reached, which required that the points of the base line be located something over 2 miles distant from the aviation field, in order to obtain angles which could be conveniently observed with an ordinary surveyor's transit. The time of the observations—late afternoon—necessitated a position south of the field in order that the observers might have the sun behind them, and made possible the utilization of high ground for the observation stations. The work was carried on under the supervision of Prof. R. W. Wilson, of Harvard University, Albert J. Holmes, an engineer of Cambridge, being stationed at the other observation point. Station *A* was located on the slope of Forbes Hill, Quincy, and Station *B* was at East Milton in an open field. Either station could be seen from the other, but as a direct measurement could not conveniently be made between them, the distance was figured from indirect measurements and was found to be 6,236 feet. The distance from the aviation field was about 2¾ miles, so that had any one of the aviators reached an altitude of 10,000 feet, his angle of elevation would not have exceeded 35 degrees.

Back of each station, in the line of the base, range poles covered with alternate strips of black and white cotton cloth and surmounted by a signal flag were erected. Around the hub marking each station, three stakes, on which to place the instrument, were driven flush with the ground, thus insuring a quick and stable set-up. Sun and wind shelters for the instruments were also provided, and telephone connections were made between the two stations and with Professor Wilson's office on the aviation field.

The recorder at each station was also the telephone operator, who was provided with a head and breast attachment for receiver and transmitter. When notice was received from the field that an altitude flight was about to be attempted, both stations were called and the standard chronometer time given. The operators' watches were compared with this standard and the result recorded. At the same time, the name of the aviator and the type of machine to be used were given. As soon as the aeroplane could be seen from both stations, the recorder at Station *A* would give the word to get ready, at which both the observers trained their instruments on the aviator himself, Fig. 34, as representing the center of gravity of the machine. An answer of "all right" was then passed back to Station *A*.

Each observer then followed the movements of the aeroplane by turning the upper motion of the transit with his left hand—the lower motion having been set at zero on the base line—and moving the telescope up or down with his right hand by means of the tangent screw on the vertical circle. The signal "all right" was repeated back and forth until the recorder at Station *A* would say "set," at which the observers would cease moving their instruments and read to the recorder the resulting horizontal and vertical angles. At the same signal each recorder noted the time to the nearest second. The recorded time reduced to standard time served to identify corresponding observations. Eight series of observations were taken on five different days during the course of the meet. While there was nothing new in the methods thus employed in determining altitude, the conditions were such as to call for smoothly-working instruments in perfect adjustment, and the observers and recorders had necessarily to be on the alert. Approximate heights obtained by sextant observation were announced on the field after each flight. Aneroid barometers and other apparatus were also used on the machines themselves, but the official altitudes were computed from the obser-

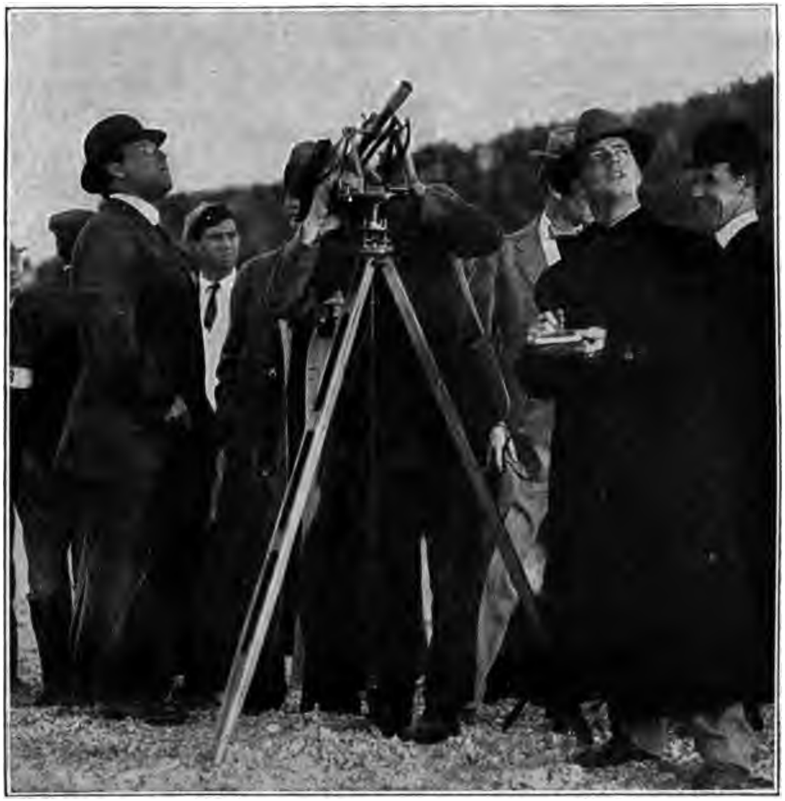

Fig. 34. Triangulation Method of Measuring Altitudes

vations described above and were made public only after having been carefully worked out at the close of the day's events. The best height reached during the course of this meet did not approach the existing record at that time. It was a flight of 3,860 feet made by Brookins in a Wright biplane. The same aviator had previously ascended over 5,000 feet at Atlantic City, his altitude being determined by the same method of triangulation here described.

The cumbersomeness of the elaborate preparations involved as well as the number of trained observers and the apparatus required for carrying out this method call for scarcely any comment. Even were it a method that could be universally applicable, or, in other words, adapted to any conditions, it could hardly come into general use, although the fact is conceded that it is the most accurate method. It will be evident that as it depends entirely for its working upon the ability of the observers to follow the aeroplane, regardless of the height it attains, the habit of rising "clear out of sight" that has been indulged in by the aviators in recent record-breaking flights would put the entire system out of commission. This would likewise be the case where there were any low clouds or mist to obscure the view.

A method of triangulation can also be employed from the aeroplane itself, but has the disadvantage of requiring an observer for this purpose, while observations would be difficult at the high rate of speed ordinarily attained by the heavier-than-air machine. The method is more applicable for use in a balloon or dirigible. It consists of observing two points of the imaginary base line of a triangle on the ground with the aid of an instrument having a graduated scale. The length of this base line, or distance between the two points on the ground selected by the observer, is evidently in inverse proportion to the distance from the observer's location in the balloon to one of the points. The observer sights an object of known dimensions, such as a house or a tree, thus measuring the apparent angle under which it is seen.

Acoustic Method. There is also the acoustic method by which rough approximations can be obtained of moderate heights. It consists in measuring the time necessary for sound to traverse the distance which separates the aviator from the ground and is likewise only applicable to the balloon or dirigible, also involving a special observer to carry it out. Any distinct noise made by the aeronauts will be deflected or echoed by the surface of the earth and returned to them after a certain lapse of time, measured by their distance in the air. By accurately noting the time required for a sharp blast on a horn to reach the earth and return as an echo, and multiplying this by the speed at which sound travels, the result obtained will be twice the distance above ground. However, since the speed of sound is 340 meters per second, it would be easy to make such serious mistakes in the observations as to render the latter entirely worthless for any practical purpose, a difference of only one-fifth of a second making a variation of more than 100 feet in height. Even though obtained by accurate observations, the result also requires changes and corrections according to the density of the atmosphere, and it may be altogether erroneous if there happen to exist ascending or descending currents of air at that point at the time the observations are made.

It will be easy to appreciate, for instance, how difficult it would have been to ascertain the heights attained in any of the attempts at altitude records that marked the close of 1910. The rivalry to be the first to attain 10,000 feet was very keen. Drexel came very close to this mark, his corrected readings showing a shortage of only a little over 100 feet. The record was finally made by Legagneux, who, soaring over Pau, France, reached a height of 10,499 feet. Then Hoxsey, in a Wright biplane, ascended almost 1,000 feet higher at Los Angeles on December 27, 1910. This represents a distance of nearly 2 miles from the earth and long before that height is reached such a small object as an aeroplane becomes invisible to the naked eye, and while it would be extremely difficult for one observer with a telescope to keep the tiny speck in view, it would be much more difficult for two to follow it constantly.

In the case of Hoxsey's record-breaking flight, his machine was completely lost to view for more than an hour, and although subsequent events showed that he had gone practically straight up over the aviation field—coming down again at the same place—it was impossible for numerous experienced observers to sight him even with the aid of strong field glasses. In fact, as the ascent was made in little short of a gale—the wind blowing forty miles an hour—it was feared that he had been blown away and surrounding towns were notified to be on the lookout for the machine. Only a few years ago, there was scarcely an aviator who dared rise in the air when there was more than a zephyr stirring, so that Hoxsey's ascent was an extraordinary feat in more than one sense, affording a striking illustration of the stability of the biplane. The same wind but a short time before had brought Latham's huge Antoinette monoplane to grief. (It was Latham who set the initial high mark for 1910 at 3,445 feet, in France.) On landing, Hoxsey was so benumbed that he could scarcely speak and had to be lifted from his seat and supported until his circulation again approached the normal.

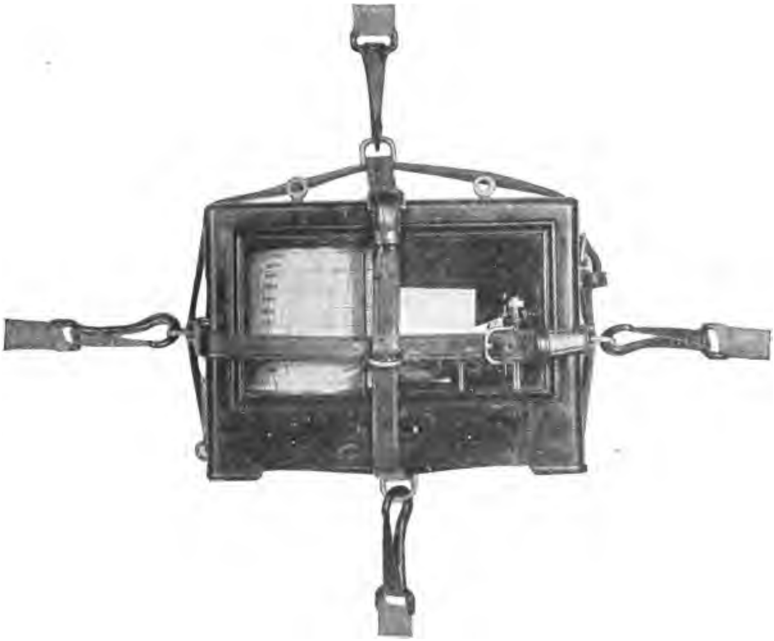

Fig. 35. Barograph Mounted so as to Prevent Vibration

Barograph. The aeroplane accordingly outgrew the triangulation method of ascertaining the height reached after it had been given a few trials. Although its accuracy is indisputable, this being the means employed by civil engineers to determine the height of mountains, it was not depended upon solely even on the occasions in question, a barograph being placed on the machine in addition. Now that invisible heights have been attained, even under the clearest weather conditions, the barograph is the only resource.

TABLE I

Fall of Barometer at Different Elevations above Sea Level

(Latitude 40 degrees)

Height above Sea Level Feet	Fall of Barometer Inches
917	1
1,860	2
2,830	3
3,830	4
4,861	5

The barograph, as its name indicates, consists of a recording aneroid barometer which for aeroplane use is housed in a light but strong glass case, as shown by Fig. 35. The aneroid barometer proper is a very delicately made and adjusted vacuum box, or rather a series of exhausted cells of very thin metal, placed one above the other. It is so delicately adjusted that it is susceptible to very slight changes in atmospheric pressure, contracting as the pressure increases and expanding as the pressure decreases, as in ascending. Its movements are transmitted through a series of multiplying levers to a pivoted lever carrying at its end a small pen and a supply of ink. This pen bears against a chart wound upon a hollow drum, the latter being revolved by clockwork. The chart is graduated according to the metric system, usually representing meters of ascent, the divisions being of one millimeter each; or in hundredths of an inch, representing feet of ascent. The abscissas of the chart mark the ascent or descent and the ordinates mark divisions of time.

A mercury barometer falls approximately 1 inch for every 900 feet of ascent, as can be seen from Table I compiled at mean atmospheric pressure in latitude 40 degrees.

But despite its sensitiveness and delicacy of adjustment, the use of the barograph is not without its drawbacks. It is affected adversely by the vibration of the motor and to guard against this various expedients are resorted to. In one of his attempts, Latham suspended the instrument around his neck—a plan that rendered it necessary to take his hands from the control in order to consult it, and one that might prove annoying in other ways. Ordinarily, it is suspended by three spring straps from guy wires or other convenient points on the machine where it will be in plain sight of the aeronaut, Fig. 35. As far back as twenty years ago Colonel Renard adopted the scheme of suspending the barometer itself inside its box or housing by means of rubber bands fastened to the different corners, thus isolating the instrument somewhat after the manner of a spider hanging in the middle of its web. The barometer thus protected was employed in connection with sounding balloons and it was found that a fall of 12 to 15 feet had no effect on it.

A further disadvantage of the barometer is what may be termed its *lag*, or *retardation*. In other words, it does not respond instantly to the change of pressure. This lag will be more or less accentuated according to the rapidity with which the altitude is attained and the pressure correspondingly modified, so that in order to obtain a correct reading at any given height a brief period must be allowed to permit the instrument to accommodate itself to the changed atmospheric conditions. The rapidity with which it will do this depends in large measure on the extent of the difference between the actual and recorded pressure at the moment. Where the variation is great the force tending to overcome the inertia of the instrument is correspondingly increased, and the atmospheric pressure may be said to accumulate a *head*, analogous to a column of water, this being true of thermal as well as barometric variation in its influence upon the recording instrument. But even with this allowance for accommodation to changed conditions, the barograph indications only approach the actual height in a varying degree, experience having demonstrated that this is almost always more or less inferior to the real altitude attained.

Since the reading of the instrument denotes only the difference in pressure between the point of departure and the altitude attained, the barograph employed must be calibrated just before being used, and its record is also subject to correction, depending upon the atmospheric conditions prevailing at the time. In fact, a resumé of the precautions observed on the occasion of Drexel's flight at Philadelphia would make it appear that this apparently very simple method is almost as elaborate as that required to obtain a similar result by triangulation. The instrument employed was a Richard, of French make, but similar in construction to the barograph manufactured by Queen and Company, Philadelphia, and illustrated here.

Being compensated for temperature, the barograph requires no correction for the effect of temperature on the instrument itself, but its reading requires correction for the effect of temperature on the atmosphere, which need be taken into consideration only when the latter is above or below 50°F. That this may be the case frequently, in fact practically always, is illustrated by the sufferings of aviators at high altitudes. In the monoplane with the motor at the head, the aviator sits directly in the blast of the propeller and it appears to be next to impossible to wear sufficient clothing to prevent suffering from the cold. Drexel, Fig. 36, wore several sweaters in addition to a specially fleece-lined skin suit. The daily press reports of Hoxsey's flight at Los Angeles mentioned that the aviator was afraid that "the carbureter of his motor would freeze," in other words, choke up with ice and stop the motor. This might have been the case with a motor of the ordinary type, but the Wright motor could hardly suffer from such a defect as it is not equipped with a

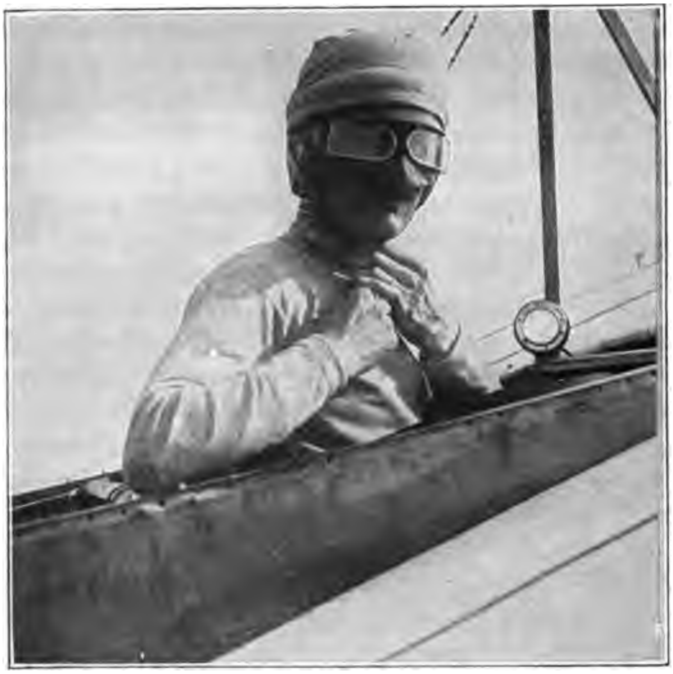

Fig. 36. Drexel Preparing for an Altitude Flight

carbureter of any kind. Instead, it is fitted with a small gasoline pump which forces the fuel directly to the inlet valve of each cylinder. As an automatic inlet valve is employed, the spring tension of the valves might prove excessive under the diminished pressure encountered at high altitudes, thus greatly cutting down the supply of air through the decrease in the maximum opening of the valve, but this does not appear to have occasioned any trouble thus far. The Antoinette motor is also fitted with a gasoline pump to feed the fuel, instead of the usual carbureter. In the case of the latter, the lowering of the temperature is aggravated by the rapid evaporation at the air intake, a tendency that has brought about a very general use of the water-jacketed type of carbureter on the automobile.

In reading the barograph, it is customary to apply, for correction of temperature, the carefully worked out tables of Sir G. Airy, late British royal astronomer. Carrying the instrument about is apt to derange it through the jolting it receives, so that in order to insure accuracy, it is necessary to calibrate it before a flight. Before Drexel's attempt at record breaking, his Richard barograph was carefully tested by the experts of Queen and Company, with the assistance of the expert of the weather bureau. This was done by placing the instrument in the receiver of a large air pump and exhausting the air. Connected with the partial vacuum in which the instrument rested was a column of mercury, which had previously been accurately adjusted for temperature, altitude, and capillarity. In the course of exhausting the air, the instrument passed through all the changes represented by an ascent from sea level, or an atmospheric pressure of 29.92, to an elevation of 15,000 feet, and was found to register in absolute coincidence with the mercurial column. The inclosing cover having a glass front and permitting the instrument to be seen, but not touched, was then sealed, and attached to the Bleriot monoplane. Immediately after the conclusion of the flight, the instrument was again taken to the laboratory and subjected to a similar test, which proved it to be in good order and correct in its indications. The following are the results of the examination:

The difference in atmospheric pressure between the upper and lower stations on the barograph record was 9.302 inches. At the time of the ascension the pressure at the ground, as indicated by the record, was 30.05 inches and at the altitude attained was 20.75

inches, giving a difference of 9,929 feet on the basis of pressure at sea level of 29.90 inches at a temperature of the air of 50°F. Making a correction to the pressure of the lower station (plus 136 feet), correction to the mean temperature of the air column (minus 205 feet), correction for the gravity at Philadelphia which is in latitude 40 degrees North (plus 5 feet), correction for moisture in the air column (plus 32 feet), we have 9,929 plus 136 plus 32 plus 5 minus 205 feet= 9,897 feet, as representing the actual altitude reached.

The temperature of the upper air is also of some importance in determining the final result, and while no recording thermometer was carried by Drexel, it just so happened that the United States Weather Bureau had its temperature kites flying from Mt. Weather at an altitude of 13,000 feet, the air currents at the time flowing from the southwest directly over Philadelphia. It was thus possible to apply an accurate correction for the temperature of the upper air stratum, there being at that altitude no local conditions to affect the result.

From the foregoing, it will be apparent that the making of an altitude record with the barograph is almost as delicate and involved a matter as determining the height by triangulation. For the comparison of records and to establish indisputably the rights of each competitor, it is essential that the results be determined with the utmost exactitude attainable. Thus Drexel's flight, while an extremely creditable performance, particularly in view of the time of year it was made, did not constitute a breaking of the record made by Johnstone in the special Wright biplane at Belmont Park a month earlier, as his increase did not exceed the new limit of 100 meters, or 328 feet, the actual difference being only 183 feet. On the other hand, the public is anxious to know results on the spot, and to satisfy the clamor the actual reading of the barograph is usually given, it being understood that such figures are subject to modification by careful verification, as precision is incompatible with rapidity.

In addition to the numerous corrections that have to be made before the record can be considered properly verified, there is also the danger of deranging the instrument through the jolts it may receive in the starting and alighting of the aeroplane. The barograph must be calibrated just previous to the ascent and verified as soon afterward as possible, the former being particularly necessary as the instrument may have been carried a long distance in an automobile or railway train, as was the case with Drexel's instrument.

Individual Barograph Records. *Johnstone.* A comparison of the experiences of aviators who have reached great heights is of interest in this connection. In making his record-breaking flight at Belmont Park, the barograph record of which is shown in Fig. 37, Johnstone was only 35 minutes in reaching the 8,000-foot level, but it took him almost an hour to ascend the remaining 1,000 feet of his flight. He descended at a terrific rate in one long dive that required only 5 or 6 minutes to bring him back to the ground—a somewhat foolhardy proceeding that might have had serious physical results, as already explained at the opening of the present subject. Johnstone kept his motor throttled coming down and accordingly did not have the terrifying experience that Brookins passed through earlier in the same meet when he was forced to descend from a height of 5,000 feet in the Wright "baby" biplane with a dead motor. The machine was considerably damaged in alighting but Brookins was unhurt.

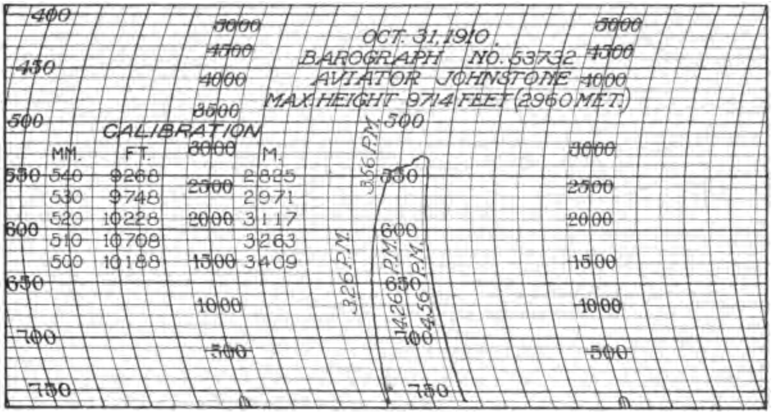

Fig. 37. Barograph Record of Johnstone, Showing Rapid Ascent

Johnstone was fond of "hair-raising stunts" such as these steep dives and lost his life shortly after as the result of a similar performance at Denver in the middle of November. On the occasion of his lofty flight at Belmont Park in October, Johnstone did not experience any discomfort from his exceedingly rapid transition from a height of almost 2 miles with its rarefied air down to the normal atmospheric pressure to which we are accustomed at sea level.

Drexel. It was otherwise with Drexel at Philadelphia. During his first attempt to break Johnstone's record, he was attacked by mountain sickness—one of the numerous fanciful appellations under which nausea travels—and, in addition, he was numb with the cold. At the time, he was at an elevation of 8,373 feet which he had attained in about 45 minutes and, as he was then over the Atlantic Ocean, he immediately started downward in long spiral sweeps, Fig. 38. The second attempt was made a few days later and it accentuated the experience which most aeronauts have encountered in rising to a great height—that is, the ease with which a certain altitude between 8,000 and 9,000 feet is attained and the difficulty met in getting any higher—as illustrated by the fact that Johnstone made his ascent of the first 8,000 feet in little over half an hour, but was almost an hour in rising 1,000 feet more.

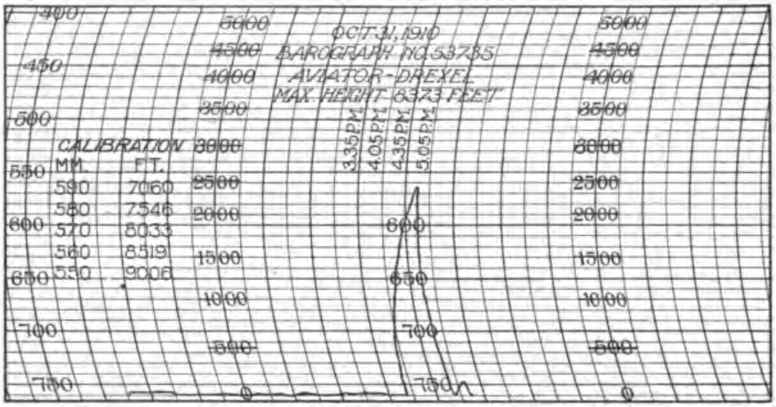

Fig. 38. Barograph Record of Drexel, Showing Rapid Ascent and Descent

When Drexel's barograph recorded within less than a hundred feet of the then coveted 10,000-foot mark, it seemed impossible to go up any higher. It will be recalled that the actual reading of the instrument lacked only 71 feet of this figure, but numerous attempts to ascend farther in spirals, as is usually done, made no impression

TABLE II

Aeroplane Altitude Records for 1910

Date	Name	Machine	Place	Altitude
Jan. 7	Latham	Antoinette monoplane	France	3,280
Jan. 12	Paulhan	Farman biplane	United States	4,165
July 9	Brookins	Wright biplane	United States	6,171
Aug. 11	Drexel	Bleriot monoplane	England	6,600
Sept. 3	Morane	Bleriot monoplane	France	8,471
Sept. 8	Chavez	Bleriot monoplane	France	8,485
Oct. 3	Wynmalen	Farman biplane	France	9,104
Oct. 31	Johnstone	Wright biplane	United States	9,714
Nov. 23	Drexel	Bleriot monoplane	United States	9,897
Dec. 9	Legagneux	Bleriot monoplane	France	10,499
Dec. 27	Hoxsey	Wright biplane	United States	11,474

whatever on it. The expedient of making a sudden dive and then shooting upward with the momentum thus gained, roller-coaster fashion, was then tried but failed to result in forcing the machine more than a few feet higher. The descent was made in a perfectly straight line at an angle which brought the machine to the ground at a point 12 to 15 miles distant from the starting field.

Legagneux. Although Drexel did not succeed in breaking Johnstone's record officially, the latter only remained valid for a very short time, Legagneux reaching a height of 3,200 meters, or 10,499 feet, within less than a fortnight later, December 9, 1910. This was accomplished in a Bleriot monoplane although this French aviator had previously been closely identified with the Farman biplane. In one of the latter machines he successfully made *Le Circuit de L'Est,* one of the leading French long-distance flights, constituting practically an aerial circumnavigation of France—a trip of several hundred miles. He also made the 180-mile flight from Paris to Brussels with a passenger in a Farman, covering the distance in slightly less than 3½ hours or an average for the distance of near 60 miles an hour, which is remarkable in view of the load carried.

Summary of Altitude Records. How rapidly altitude records followed one another during the year 1910 will be evidenced from a glance at Table II.

As the new rule making necessary a difference of 100 meters to constitute an official record went into effect only a short time before

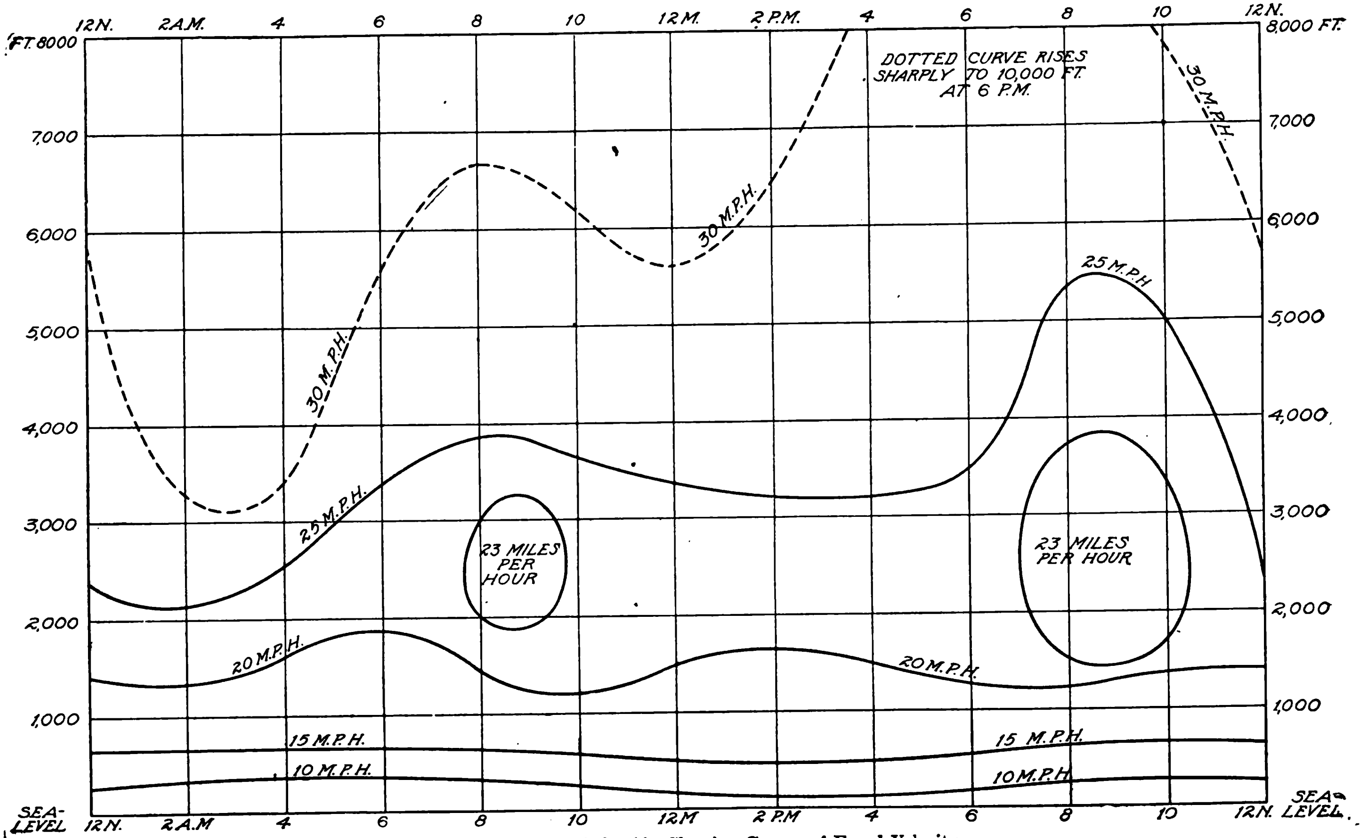

Fig. 39. Wind Chart of the Air, Showing Curves of Equal Velocity

Drexel's flight at Philadelphia, those preceding his accomplishment were officially regarded as setting up new altitude marks regardless of the slight difference that may have actually existed between the new height attained as compared with the one just given. This is noticeable in the flights of Morane and Chavez—the latter of whom made his record in crossing the Italian Alps—there being a margin of only 14 feet. This, taken in connection with the numerous corrections necessary in the reading of the barograph before the actual height attained can be accurately calculated, makes apparent the wisdom of the rule in question.

That the instruments will give remarkably uniform results when carefully checked, however, may be noted from the experience of the International Aviation Meet at Belmont Park, in October, 1910—one of the most important events of the year. At times, there were as many as eight or ten machines of different types in the air at once. All of the altitude instruments used were carefully calibrated in advance by Major Samuel Reber, U. S. A., who served as a member of the Contest Committee of the Aero Club of America. The formula of Laplace was used in this work and, as the corrections for temperature were allowed, the results as shown by the barograph records were practically correct. Each instrument was calibrated separately, the readings being checked at every 50 millimeters on the chart. So accurate were the results thus obtained, that two barographs sent aloft on the same aeroplane varied from each other by only 13 feet, or less than the width of one of the recording lines which were equivalent to a height of 17 feet.

In view of what has been accomplished in less than a dozen attempts spread over the course of a year, it would be futile to attempt to predict what the next few years may bring forth in altitude records. With a water-jacketed carbureter to prevent freezing at the low temperatures encountered at great heights even in midsummer and a means for compensating for the increasing rarity of the air in order to prevent the efficiency of the motor from falling off too rapidly, as the supply of oxygen decreases in proportion to the volume of air, there would appear to be only one limit to the heights attainable—that of human endurance. Adapting the motor to the extreme range of conditions under which it must operate in traveling from sea level to an altitude of 2 to 3 miles or more without serious loss of efficiency, is an apparently simple matter. In addition to the precautions against freezing, means have to be provided for mixing a very much greater volume of the rarefied air with the gasoline in order to maintain the supply of oxygen at a point where it will be sufficient to create an explosive mixture of equal power to that normally obtainable at much lower levels. Otherwise, there would appear to be no difficulty in running the motor with practically the same power output, regardless of the height attained. Adding to these precautions the fact that at certain points the characteristic hourly wind velocities for different altitudes have been obtained, as shown in Fig. 39—a sort of chart of the air which will warn the aviator of the dangers he is liable to encounter—it seems as if all of the difficulties except those inherent in the aviator himself had been guarded against.

The ability of the human organism to withstand the sudden transition from normal atmospheric pressures to a very low pressure, and *vice versa,* without serious physiological results, is a different matter. There are undoubtedly individuals who are but slightly susceptible to this or, at any rate, very much less so than others, as witnessed by Johnstone's experience, and with inducements in the form of cash prizes, these aviators are likely to come forward. At present the heights attained represent only about a third of the distance reached in ordinary spherical balloons and slightly more than this proportion of the altitudes reached in mountain climbing, Fig. 31. It is true that bleeding at the nose and ears, and even loss of consciousness, has resulted from reaching extreme altitudes in a comparatively short time, as where a balloon has suddenly shot up to a great height. Being overcome in this manner would naturally end fatally in the case of the aeronaut who has to be alert every moment in order to insure his safety. He has no sheltering basket in which he can safely remain inert until the recurrence of normal conditions revives him. Despite these dangers, it seems quite probable that the course of the next few years will mark the attainment of great heights in a heavier-than-air machine—in fact, altitudes marking the limit beyond which human life can not be sustained. It is no longer a question of mechanics nor of confidence in the ability of the machine to accomplish what is demanded of it, but merely one of human endurance.

Although the air has the apparent advantage of being a highway without hills, it is evident that there is more need for climbing than on solid ground, and this need will increase with the number of aviators until it will become necessary to go up or down to avoid machines approaching from other directions. Climbing, in fact, is one of the first feats to be mastered for at the very start the aeroplane must be driven upward to clear obstructions. If the angle of ascent be too great, the machine may very quickly lose headway and come to a standstill, under which circumstances a sudden slant in almost any direction might result with an inexperienced driver and would probably be followed by a fall. The latter would be caused by the almost total loss of the effective supporting surface through such a radical alteration of the angle of incidence.

This, and the experiences of Johnstone, Drexel, Hoxsey, and others who have ascended to great heights, suggest the importance of employing a gradometer on the machine. When these aviators went out of sight of the ground, and particularly when enveloped in a cloud, they found it difficult to determine whether the machine was heading up or down, except when the angle was acute enough to be readily perceptible. The gradometer as used on automobiles is nothing but a small spirit level with a scale calibrated to indicate the angularity of ascent or descent in degrees. Every machine has its peculiarities and there is an angle at which it climbs most effectively, while in the case of fog close to the ground it would be of great assistance to the aviator by indicating whether the aeroplane was approaching the ground or the reverse.

EXAMINATION PAPER

AERONAUTICAL PRACTICE

PART I

Read Carefully: Place your name and full address at the head of the paper. Any cheap, light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper; use your own words, so that we may be sure you understand the subject.*

1. What are "wake effects"?
2. By what means may stability be increased?
3. What shape should a tail rider plane preferably have?
4. What is a damping couple? In what proportion does its control torque change?
5. How must the center of pressure and the center of gravity be related to each other to insure stability?
6. Describe "volplaning."
7. What is automatic stability?
8. Mention some of the various methods that have been employed to attain automatic stability.
9. Briefly describe the Wright system of automatic stability.
10. Describe the gravity principle in connection with automatic control.
11. Give a short description of the Éteve Stabilizer.
12. How may the gyroscope be employed to effect automatic stability in an aeroplane?
13. In view of what has been done, will some form of automatic stabilizing device be a necessity? Give reasons.
14. What dangers does the aviator encounter in regard to his physical system when descending or ascending too fast?
15. Why is the method of ascertaining the altitude of an aeroplane by triangulation obsolete?
16. Describe the barograph and state the principles on which it works.